Quantifying Land-use / Land Cover Change and Eutrophication in the Carleton River Watershed, Yarmouth County, Nova Scotia, Canada

Environmental Science Undergraduate Thesis

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Abstract

A number of rivers and watershed systems in Southwestern Nova Scotia, Canada have experienced an increase in eutrophication promoting nutrients over the past three decades. As a consequence, artificial eutrophication and algal blooms have gained prevalence within these local systems and have prompted concern over the environmental and human-health consequences surrounding them. Studies have shown that eutrophication can be correlated with land-use / land cover changes. Anthropogenically-induced eutrophication can result when an environment becomes inundated with excess nutrients, such as phosphorus, from residential, industrial or agricultural operations. These excess nutrients boost primary productivity and can cause algal blooms and increased plant growth. Due to high turnover-rates, the subsequent death and decays of these algae and aquatic plants can then result in increased biological oxygen demand and oxygen deprived environment, with a reduced capacity to support aquatic species.

This study examines the extent to which land-use / land cover change has occurred in the Carleton River Watershed and attempts to determine if there is a relationship between water quality and land-use / land cover change. Remote sensing imagery and geographic information systems (GIS) were used to analyze land-use / land cover change, ultimately using the 'forest' informational class as a proxy for land-use / land cover change. A secondary analysis of water quality data was conducted using Statistical Package for the Social Sciences (SPSS). Inferential statistical test results show that there has been significant change with respect to the water quality indicators (total phosphorous, total nitrogen, nitrite-nitrate and pH), additionally showing that location is positively correlated with total phosphorus and nitrite-nitrate. Further analysis of landscape metrics using the FRAGSTATS software package, showed that the forest in Southern Nova Scotia is dynamic and has changed, in a ways that promote fragmentation, over the past 30 years. Ultimately land-use / land cover and water quality have both changed over the years, allowing for the conclusion that land-use / cover change within the Carleton River watershed has the potential to be related to changes in land-use / land cover.

1.0 Introduction

1.1 Motivation

Changes in land-use / land cover have been facilitated and intensified by advances in technology and the ever pressing need to provide for the expanding global population. For example, the Haber-Bosch process has greatly increased the input of ammonia to the environment and resulted in the intensification and expansion of agricultural operations (Kandemir, Schuster, Senyshyn, Behrens, & Schlögl 2013). These advances influence nutrient loading in aquatic systems and result in eutrophication, impacting ecosystems across the globe, threatening fish stocks in the Gulf of Finland and the Gulf of Mexico and altering reef ecosystems in the Red Sea (EPA, 2015; Naumann et al,. 2015; Rahikainea et al., 2017). Looking beyond the global scale, anthropogenic eutrophication and algal blooms have become increasingly prevalent within local systems, prompting concern surrounding potential environmental and human health consequences (EPA, 2015). Algal blooms can be evidence of eutrophication, which can negatively impact aquatic ecosystems by creating an anoxic environment and diminishing the ecosystems ability to support aquatic life (Chorus & Bartram, 1999). Furthermore, algal blooms can have negative effects on human health (Moore et al., 2008). Cyanobacteria (formerly known as blue green algae) can produce toxins that can irritate the eyes and skin, and if ingested can cause fever, nausea and vomiting (NS Environment, 2011).

Eutrophication can result from a variety of anthropogenic activities, particularly activities that generate and discharge phosphorus to freshwater systems (Schindler, 1974). While phosphorus enters the biosphere naturally through weathering, these slow moving sedimentary processes cause phosphorus to be a limiting nutrient, especially in freshwater systems (Bennett, Carpenter & Caraco, 2001; Carpenter, 2008b). Alternations to land use and cover can amplify bioavailable phosphorous and, in turn, increase biological production (Bennett, Carpenter & Caraco, 2001; Carpenter, 2008b). Agricultural land-use activities are particularly influential to adjacent surface water systems as phosphorus and nitrogen are components in fertilizer, nutrients not absorbed by crops are captured in runoff and enter local waterways, altering water quality with the potential to promote eutrophication (Fierro et al., 2017; Carpenter, 2008a; Lavelle, Dugdale & Scholes, 2005).

It has been demonstrated by Ierodiaconou et al. (2005) that some land-use types, and / or changes in land-use, can result in degraded water quality through the emission of excess nutrients know promote eutrophication, thus establishing a clear link between phosphorus and land-use / cover change. This understanding focuses the investigation on human-environment interactions, quantifiable through changes in water quality and land cover change.

Several river systems and their associated watersheds in Southwestern Nova Scotia, Canada have experienced increases in total phosphorus levels over the past three decades (Taylor, 2010). Notably there has been a growing number of reports of algal blooms within the Carleton River system (Environment Canada, 2004; Taylor, 2010). The Carleton River system is geographically situated in Southwestern Nova Scotia and serves as a tributary of the larger Tusket River system. There are a range of land-uses within the watershed, including pockets of agricultural, industrial and residential areas (Taylor, 2009). Degradation of water quality was first noted in the early 1980s and residents have reported increased instances of algal blooms since then (Taylor, 2010). While a community science group, the Tusket River Environmental Protection Association (TREPA) has documented water quality, to date no study has attempted to quantify land change and the impact it has had on the Carleton River system. In this study, land cover change, specifically the forest change, will be used as a proxy for quantifying changes in anthropogenic activities and land cover within the Carleton River system, then further analyzed in conjunction with water quality in the system to determine if there is a link between land-use / land cover change and water quality within the system.

1.2 Background and Definitions

Depending upon the nature of land cover change, freshwater ecosystems can experience a transition from normal productivity to above-normal productivity through the fluctuation of nutrient inputs to the system (Lavelle, Dugdale, & Scholes, 2005). As land cover changes, such as through the removal of trees, ecosystems are subjected to increased erosion which in turn increases the release of nutrients into neighboring water bodies (Fierro et al., 2017). Additionally, changes in land-use such as the intensification of agriculture, can promote human-induced nutrient loading (Carpenter, 2008a; Fierro et al., 2017; Lavelle et al., 2005). Recognizing that humans disproportionately favor living proximal to water ways and have undertaken considerable development within these environments, these human-induced changes have been shown to force ecological changes, such as increased instances of eutrophication and pollution (Salas et al., 2000). Thus it has been concluded that land-use / land cover changes resulting from human activities are a major motivator in global environmental change (Turner et al,. 1994). This study applies the definitions provided by Loveland et al. (2012), with "land-use" referring to the nature in which humans utilize the environment and the resources it provides; and "land cover" as a characterization of the biological, ecological and physical characteristics of the land. When humans alter natural systems, this is considered "land change" (Loveland et al., 2012). Lastly the following definition of catchment will be utilized, a catchment is a defined area in which all precipitation that falls within its boundaries ultimately flows through a singular terminal point (EPA Ireland, 2018).

Within this context, eutrophication is the amplification of naturally occurring biological production, resulting from increased nutrient levels. This increase can the products of naturally fluctuating biogeochemical cycles and / or anthropogenic inputs to the system (Chorus & Bartram, 1999). The primary nutrients of concern with respect to eutrophication in freshwater ecosystems are phosphorus and nitrogen (Chorus & Bartram, 1999), and the increased productivity associated with eutrophic conditions can result in algal blooms. This increase in biological activity has been linked to increased plant growth, the ultimate decay of these organisms can deplete dissolved oxygen, thus creating an environment that is unable to support aquatic species (Chorus & Bartram, 1999).

Within the Carleton River system there are several distinct forms of non-point source and point source pollution that need to be considered: mink farms, other agricultural operations, aquaculture and residential sources (Taylor, 2009). A particularly contentious source of excess nutrients is the waste generated from mink farms results from manure and waste feed (Medel, 2012). For economic reasons many farmers choose to stockpile the manure, the composting of the manure results in nitrogen and phosphorus leachate (Zarkadas, Dontis, Pilidis & Sarigiannis, 2016). This leachate can act as a vector for limiting nutrients to surface waters, with further potential to contaminate subsurface water supplies (Zarkadas et al., 2016). In a global context, agriculture has been shown to be a primary source of flux in the phosphorus and nitrogen cycle, with excess nutrient runoff attributed to the application of fertilizer to agricultural lands (Hart, Quin & Nguyen, 2004; Nova Scotia Environment, 2011).

Residential areas can also act as an additional source of excess nutrients (Dennis, 1986). Dwellings that sit outside the reaches of city / municipal sewer systems, as is the case within most of the Carleton River watershed, typically utilize septic tanks and weeping beds as a means of waste collection and storage; these septic tanks in turn act as a source of nutrient pollution (Nova Scotia Environment, 2011). Transported within the effluent of septic tanks are a range of nutrients such as carbon, nitrogen and phosphorus (Richards, Paterson, Withers & Stutter, 2016). Upon discharge these nutrients can then contribute to the nutrient loading and eventual eutrophication in receiving waters (Richards et al. 2016).

1.3 Summary of Literature and Knowledge Gaps

A study by Taylor (2010) illustrate that phosphorus concentrations within the Carleton River system have been increasing over the past three decades, with more recent phosphorus values (e.g., 2009) elevated in comparison to 1983 values. Further concluding that the increase in phosphorus concentrations are likely the result of human induced nutrient pollution. Recognizing that in most instances lakes located near the headwaters of river systems experience lower nutrient levels and, in turn, lower productivity (Taylor, 2010). However, in the Carleton system the majority of phosphorous enters the watershed in its upper sections, an area housing the highest number of mink farms within the system (Brylinsky, 2012b). The Carleton system shows a nutrient gradient in which nutrient levels decrease as the water moves downstream (Taylor, 2010). While Taylor (2010) categorized the nutrient gradient in the Carleton system as “atypical” and there is a general concuss that nutrient concentrations increase with distance from headwaters, there is a need to consider additional stream / lake characteristics that may contribute to this particular nutrient gradient in the Carleton system. For example, stream morphology and bathymetry can influence biogeochemical cycling within aquatic systems and thus may alter nutrient gradients (Ryan & Boufadel, 2007).

Economic importance of land and land-use is a key driver behind land-use changes on a local and global scale, the greatest economic applications include: agricultural operations, livestock, human settlements and resources extraction operations (Turner et al., 1994). While agriculture inputs to the system are not solely the production of mink farms, these operations are an important component of the region's economy. Moreover, the region is also populated with several small-scale farming operations, which need to be considered when assessing nutrient loading within the Carleton River system (Taylor, 2009). In a review of phosphorus runoff from agricultural lands, Hart et al. (2004) concluded that phosphorous released during specific events (e.g., heavy rainfall) may have greater effects than previously realized, warranting additional consideration in future assessments. Furthermore Hart et al. (2004) expressed the need to further assess specific nutrient sources when conducting overall assessments. Lastly, Turner et al. (1994) concluded that specific regional and local case studies are needed to account for cause-cover relationship at all ecosystem scales.

1.4 Introduction to Study

The overarching research question that guided this study was: *How has land-use cover / land-use change impacted eutrophication in the Carleton River Watershed, Yarmouth County, Nova Scotia, Canada?* The purpose of this research question was to assist in gaining an understanding of how human activity and corresponding land cover change, can impact neighboring aquatic ecosystems.

The goal of this study was to quantify land-use / land cover change and eutrophication within the Carleton River system, Yarmouth County, Nova Scotia, Canada. The following sub-question was used to further guide the study:

- How has land-use/cover (quantity and type) changed in Yarmouth County, Nova Scotia, Canada over the past three decades, with respect to land surrounding sizable freshwater systems?
- Has land-use / land cover change impacted algal blooms in this freshwater system?

The geographic scope of the study consisted of a series of sizable, connected freshwater bodies within the Carleton River system, with respect to eutrophication and water quality analysis. For land cover / land-use, a regional scale was used, consisting of the Southern Nova Scotia, Yarmouth and Digby Counties. The temporal timeframe for the study went back 32 years, between 1983 and 2015, with respect to water quality and spans 30 years with respect to land cover / land-use analysis, between 1987 and 2017.

1.5 Summary of Approach

This study addressed the research objectives through a quantitative analysis of land cover change and water quality data, with a focus on nutrients known to contribute to eutrophication. Classification of remote sensing imagery and change detection analysis was used to assess change in land cover over the study period. Inferential statistical analysis of water quality data was performed to understand changes in water quality parameters. These two avenues of analysis were examined in tandem to draw a cursory conclusion about the connections between land-use / land cover change and eutrophication within the Carleton River system.

2.0 Literature Review

This literature review will provide an overview of land-use / land cover change and related implications for eutrophication and algal blooms. Once established, applicability to the empirical focus of Carleton River system in South Western Nova Scotia is reviewed. A general overview of eutrophication is then provided, specifically investigating the role of excess nutrients, phosphorus and nitrogen. The Carleton River watershed is further characterized through the examination of water characteristics in the system as well as land-use and recent nutrient patterns within the system. This review broadly examines how land-use / land cover can influence nutrient inputs, eutrophication and algal blooms, and how these broader ideas can be applied to the Carleton River system. Furthermore, knowledge gaps in the literature are identified and discussed, with a focus on how these gaps can be addressed. Finally, limitations and their potential impact on the study are explored.

2.1 Freshwater Eutrophication and Algal Blooms

Collectively, a connection has been established between eutrophication and the increased frequency of algal blooms in freshwater systems (Chorus & Bartram, 1999; Schindler, 1974, 1977; Schindler et al., 2008). For example, Chorus & Bartram (1999) concluded that increased nutrient levels result in eutrophication. Additionally, it has been shown that the appearance of dense or floating algal blooms, high turbidity and increased anoxia, can be signs that eutrophication may be taking place (Schindler, 1997; Schindler et al., 2008). These increased nutrients can be sourced from agricultural / storm water runoff, industrial / wastewater effluent, faulty septic systems and household fertilizer, with phosphorus being the primary nutrient of concern when emitting nutrients released from these processes (Chorus & Bartram, 1999; Nova Scotia Environment, 2011). This understanding stems from Schindler's (1974) Experimental Lakes study which demonstrated that phosphorus was a primary cause in eutrophication in freshwater lakes. Following this initial study, Schindler (1977) further demonstrated the influence phosphorus has with respect to eutrophication, illustrating this by shifting the Nitrogen to Phosphorous ratio (or N:P ratio). When the ratio of phosphorus increased in the lake it facilitated the development of algal blooms, however this was not the case with nitrogen. Thus, the input of excess phosphorus into a system can result in increased occurrences of cyanobacteria blooms (Chorus, I. & Bartram, J., 1999). The death and decay of the cyanobacteria during blooms depletes dissolved oxygen, creating a toxic anoxic environment in which aquatic life has a higher risk of mortality (National Research Council, 1996). Furthermore, algal blooms release toxins that can endanger humans and livestock (Environment Canada, 2004). Overall these studies reinforce that phosphorus is the nutrient responsible for causing eutrophic conditions and subsequent algal blooms. Through understanding sources of phosphorus and other nutrients on a local and regional scale, a better understood of how to mitigate their negative effects can be attained.

2.2 Land-use / Land Cover Change

Human-induced land-use / land cover change can have wide-ranging environmental implications from the structural alteration of local ecosystems (e.g., forest and rangeland degradation), to climate change across a range of scales (Lambin et al., 2001). A study by Sala et al. (2002) concluded that changes in land-use will have disproportionately large impacts near waterways and riparian zones, even in sparsely populated areas through increased nutrient loading, increased sediment and contamination. Similarly, Costa, Botta, & Cardille (2003) concluded that deforestation within the Tocantins River Basin, Brazil resulted in an increase in river discharge. This increased discharge was accompanied by increases in sedimentation and nutrient loading, as vegetation is no longer able to prevent erosion (Costa et al., 2003; Foley et al., 2005). Furthermore, human induced land cover change and land-use are key contributors to global environmental change, influencing ecosystems and climates on a local, regional and global scale. (Turner, Meyer, & Skole, 1994; Turner et al., 1994).

2.2.1 The Influence of Land-use/Cover Change Over Algal Blooms and Nutrient Loads

With a foundational understanding established, we can begin to understand how land-use / land cover change can impact nutrient loading and in turn eutrophication and algal blooms. Examining land-use / land cover changes associated with agricultural operations reveals that these changes can play an important role in increased nutrient loading and, in turn, potentially trigger algal blooms in freshwater systems. Some types of land-use can have particularly negative consequences for freshwater ecosystems, especially within catchment areas (Fierro et al., 2017).

Agricultural practices contribute to new fluxes in both the nitrogen and phosphorus cycle, primarily through the addition of fertilizer (Howarth & Ramakrishna, 2005). It has been concluded that phosphorus lost during specific events (e.g. rainfall) might be greater in quantity and more significant than originally thought, thus the amount of phosphorus and nitrogen originating from agricultural operations may be considerably underestimated (Hart, Quin, & Nguyen, 2004). In addition to synthetic fertilizers, animal waste can provide an additional contribution from agricultural operations. When untreated, this waste can be a notable source of phosphorus and nitrogen, periodically released to the surrounding environment (Howarth & Ramakrishna, 2005). For example, the stockpiling and ultimate composting of mink manure acts as a source of nitrogen and phosphorus within the Carleton system, the addition of such nutrients ultimately has the potential to facilitate algal blooms and eutrophication along with contamination of subsurface water (Zarkadas, Dontis, Pilidis & Sarigiannis, 2016). In addition to more traditional husbandry operations, Strain & Hargrave (2005) concluded that the excess nutrients discharged from aquaculture operation can also increase nitrogen and phosphorus levels within local aquatic ecosystems. Nutrients stemming from aquaculture operations can promote growth of microalgae and phytoplankton, ultimately reducing dissolved oxygen levels well below saturation to the point there is stress to aquatic life (Strain & Hargrave, 2005).

Agricultural activities are by no means the sole provider of excess nutrients to an ecosystem. Effluent from septic tanks can also contribute to eutrophication and cosmetic fertilizers applied to residential properties both act as sources of nutrient pollution originating from residential land use (Richards, Paterson, Withers, & Stutter, 2016). Recognizing that residential fertilizer is similar in nature agricultural products and septic tanks typically have elevated levels of inorganic nitrogen (N), phosphorus (P) and carbon (C) in their effluent, it can be concluded that septic tanks and acts additional sources of nutrients within this system (Richards et al., 2016).

Understanding that phosphorus naturally enters the biosphere though the weathering of geological formations, anthropogenic activities such as mining and land disturbances can also contribute to additional phosphorous inputs to the biosphere (Bennett et al., 2001; Carpenter, 2008b). It has been demonstrated that freshwater water systems that pass through agricultural land-use catchments are significantly more effected by land-use changes, rainfall as well as irrigation can prompt particulate matter, carry excess nutrient, to enter neighboring waterways ultimately effecting water chemistry and potentially eutrophication (Fierro et al., 2017). This excess sedimentation has also been shown to decrease light availability for aquatic and benthic communities (Water and River Commission, 2000). These aquatic communities can further be influenced by temperature changes triggered by an influx of particulate matter (Baillie, Collier & Nagels, 2005). Lastly, the destruction of the riparian zone, which is the area that separates "the water body from the upland vegetation" and includes vegetation that favors a damp environment, can directly and indirectly impact water quality (Agriculture and Agri-Food Canada, 2014; Fernández, Rau, & Arriagada, 2009; Foley et al., 2005). Concluding that land-use / land cover change motivated by agriculture has the greatest impact on freshwater systems and it is the primary provider of anthropogenic nitrogen and phosphorus inputs and recognizing that this pattern can be extrapolated to land-use/cover change across a variety of spatial and temporal scales (Carpenter et al., 1998; Matson, Parton, Power & Swift, 1997).

2.3 Carleton River System

2.3.1 Characterization of the System

The geography, anthropogenic uses and landscape characteristics of the Carleton River system play an important role in investigating how strongly related land-use / land cover change and eutrophication are within the system. The Carleton River, located in South Western Nova Scotia and is a tributary to the Tusket River system. Its watershed is approximately 200km^2 and contains roughly 100 lakes (Taylor, 2009). The upper Carleton River has been described as hydrologically complex, consisting of a plethora of lakes, streams and wetlands (Brylinsky, 2012a).

While the land within the watershed is mixed in both land-use and land cover, much of the land is forested, in addition to limited agricultural and residential pockets. These residential areas can be further characterized by their sparse populations and rural nature (Taylor, 2009).

Notably, nearly 40 mink operations are positioned near the headwaters of the Carleton River, these mink farms have been a source of social contention due to their perceived role in local environmental degradation (David Suzuki Foundation, 2011). Overall this freshwater system demonstrates atypical nutrient patterns, with anthropogenic nutrient loading in the headwater and decreasing nutrient concentrations as the water progresses downstream; in an undisturbed system, nutrients tend to exhibit the opposite pattern, with increasing concentrations as water progresses downstream (M. Brylinsky, 2012b). Adding to the complexity of the system, wetlands in the watershed contribute dissolved organic substances, while poorly buffered soils facilitate the acidification of surface water (Taylor, 2009). Finally, the entire region has been subjected to acid deposition resulting from industrial operations in the Eastern portion of the United States and Canada, which in combination with poorly buffered soils results in low pH values in surface water (Taylor, 2009). In summary, both local and regional anthrophonic impacts appear to have impacted the natural patterns of the Carleton River system.

2.3.2 Recent Patterns of Nutrient Levels, Eutrophication and Algal Blooms

Detailed studies of lakes in the region were conducted annually between 2008 and 2015, patterns of eutrophication, nutrients and algal blooms across the system emerged from these studies (M. Brylinsky, 2012a; M. Brylinsky, 2012b; Sollows, 2015; Sollows, 2016; Taylor, 2009; Taylor, 2010). Beginning in the 1980s, lakes in South Western Nova Scotia have experienced decreasing water quality due to increased nutrient loading (Taylor, 2010). Overall, nutrient levels in lakes within the watershed have been, and continue to be, impacted by human activities with the upper reaches of the watershed experiencing the greatest amount of nutrient enrichment (Taylor, 2010; M. Brylinsky, 2012a). Many of the lakes in the region have experienced increased levels of cyanobacteria, this increase has in some instances resulted in visible blooms, notably

Hourglass Lake and Ogden Lake in 2014. Noting that even if a lake does not produce visible blooms it many have still exhibited eutrophic characteristics (Sollows, 2015; 2016). However, other factors outside of cyanobacteria, such as turbidity, need to be considered when examining the formation of visible blooms (Sollows, 2016).

2.3.3 Anthropogenic Nutrient Sources in the System

Agricultural, industrial and residential areas along the Carleton River each possess the ability to adversely influence nutrient loading within the system, promoting eutrophication and algal blooms, through the addition of nitrogen and phosphorous. While aquaculture has been shown to increase inputs of phosphorus and nitrogen into aquatic systems beyond their normal ranges, there is no indication that the aquaculture operation discharging into Hourglass Lake has adversely altered water chemistry (Strain & Hargrave, 2005; Taylor, 2009). In this situation, past assessment reports have concluded that discharges from this singular aquaculture operation within the system does not greatly contribute to the observed increase in phosphorus levels (Brylinsky, 2012a).

Additionally, the area contains a few small agricultural and industrial operations, along with small pockets of residential developments (Taylor, 2009). While there has been a great deal of speculation as to the reason behind water quality degradation within the Carleton River system, there has been no studies conducted that can confidently link increases in nutrient loading to an exclusive source, recognizing that each of these anthropogenic inputs have the potential to adversely affect the nutrient levels of Carleton River watershed.

2.3.4 Analyzing Water Quality

The methods employed for the water quality analysis were centered on inferential statistics, recognizing that the approach in this work differs from previous regional studies which center their conclusions within the overall trends of water quality parameters not the significance of their change (Brylinsky 2012a; Brylinsky 2012b; Sollows, 2015; Sollows, 2016; Taylor, 2009; Taylor, 2010). There is a consensus that nutrient concentrations have increased over the past thirty years; recognizing this consensus, the present study focuses on whether these observed increases are significant statistically.

2.4 Knowledge Gaps

Studies at the local (i.e., community) and regional (i.e., county, watershed) level can illuminate specific relationships between land-use / land cover and water quality, through providing the necessary spatial and temporal resolutions. Recognizing the most revealing studies focus on individual regions over shortened temporal scales (Turner et al., 1994). Additionally, Hart et al. (2004) stressed the need to assess specific nutrient sources while conducting localized or regional studies. An assessment of a selection of nutrient sources has been done, in part, in the Carleton River system through the examination of the sole aquaculture operation within the system; however, the conclusion was that the operation was likely not responsible for increased phosphorous levels downstream (Brylinsky, 2012a). While it must be emphasised that more in-depth assessments are required, such assessments lie beyond the scope of this study.

Many studies speculate to the role of mink farms and their link to eutrophication and algal blooms, though none explicitly examined point of source discharges from these operations, their assumptions are based on geographical position and concentration of mink farms (Brylinsky, 2012a; Brylinsky, 2012b; Sollows, 2015; Sollows, 2016; Taylor, 2009; Taylor, 2010). Examining the entire system reveals evidence of an increase in nutrient loading in South Western Nova Scotia lakes beginning in the 1980s, however the data used to reach this conclusion is sporadic in nature and comprehensive studies did not begin on an annual basis until

2008 (Sollows, 2015; 2016; Taylor, 2010). The sporadic nature of the data was ultimately a limitation in this study, reflected in data gaps and breaks in the temporal scope. Furthermore, while these studies provide snapshots of nutrient patterns within the Carleton River system over varying time scales, none address the implications of land-use / land cover change within the system and its implications not only for nutrients but also on eutrophication and algal blooms.

2.5 Implications

Anthropogenic activities drive land-use / land cover change, which in many instances perpetuates environmental degradation and climate change. Looking specifically at eutrophication it has been illustrated that land-use and land cover changes can contribute to increased levels of nutrients in freshwater aquatic environments (Bennett et al., 2001; Carpenter, 2008b; Matson et al., 1997). In understanding the drivers of eutrophication and the implications of land-use and land cover change, it clear that they are inextricably linked. However, it is also understood that the resulting implications of this interaction are highly dependent upon geographic context. Within the Carleton River watershed, this study is not designed to pinpoint nutrient sources that are responsible for increased nutrient loading, but instead examines the significance of changes in water quality and endeavored to understand the relations between nutrient levels and land-use/cover change within the watershed. In doing so this study sets the stage for further investigation in the region, further providing a tool for local environmental groups and policy makers as they seek to address change on a more regional scale (i.e., Yarmouth and Digby Counties). Overall, the utility of studies at a regional and local level should not be underestimated, but the limitations must be acknowledged and used to influence continuing research and an greater understanding of the link between land-use / land cover change and eutrophication on a local, regional and global scale (Turner et al., 1994).

3.0 Methods and Materials

3.1 Overview

This research aimed to quantify land-use and land cover change and determine the significance of changes in water quality within the Carleton River system. This study was done through two parallel analysis, land-use / land cover change analysis and water quality analysis. Land-use and land cover change were analyzed using remote sensing imagery, specifically though quantifying fragmentation of the forest in Southern Nova Scotia. Water quality analysis examined levels of phosphorus and nitrogen and tested for significant differences through inferential statistical tests (i.e., sample means testing). The understanding that land-use and land cover change can result in increased nutrient levels in neighboring watersheds served as the basis for this comparison (Bennett et al., 2001; Carpenter, 2008b; Matson et al., 1997). Utilizing landscape class metrics to analysis land-use / land cover change and means statistics testing for water quality data analysis, it will be possible to attain a cursory understanding of change the forest class and the significance of the time-series water quality data. Through this analysis the impacts of land-use and land cover change on eutrophication within Carleton River Watershed became better understood, ultimately providing a basis upon which common answer can be built. Further creating a platform form future analysis with respect to the causative nature of nutrient loading and a means through on which policy decisions can be made in the future.

3.2 Study Area

With respect to water quality analysis, this study focused on 10 lakes: Vaughan, Sloans, Fanning, Ogden, Parr, Porcupine, Placides, Hourlgass, Nowlans, and Provost. Noting that

Provost and Nowlans are situated outside of the Carleton River watershed but were included as they were examined in the previous studies upon which this water quality analysis was built. The land cover change analysis focused on the Southern portion of Nova Scotia (i.e., largely Yarmouth, Digby and Shelburne Counties), with the analysis expanding beyond the land encompassed within the Carleton River Watershed.

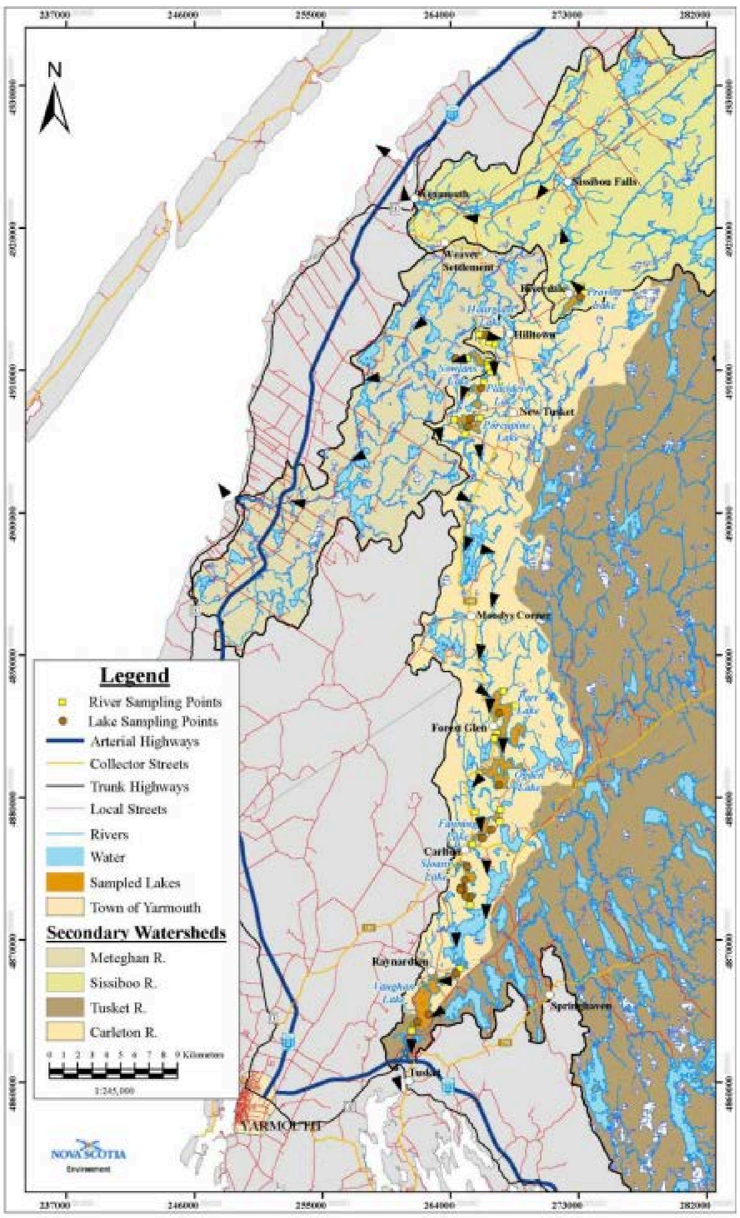

Figure 1: The Carleton River Watershed is shown here with respect to adjacent local watersheds, lakes surveyed between 2008 and 2010 are indicated (Figured retrieved from Brylinsky, 2012b).

3.3 Data Collection, Description, Justification of Methods and Analysis

3.3.1 Water Quality

Secondary data analysis provided the analytical basis for this project due to time constraints and limited resources. Water quality data was gathered from previously published regional assessments, so the data represents non-probabilistic convenience sampling. The primary sources of data were the following studies: Brylinsky (2012a), Sollows (2015, 2016), and Taylor (2009,2010). The amalgamation of similar water quality parameters, total phosphors(mg/L), pH, and total nitrogen(mg/L) or nitrite-nitrate (mg/L), provided the basis of the water quality analysis for the Carleton River Watershed. Noting that all samples included were taken within a lake and any location within the lake were eligible for analysis, but stream values for excluded for they were not included across all studies of interest. Additionally, each sample included need to include at minimum a total phosphorus, and total nitrogen or nitrite-nitrate measurement. Simple inferential statics, means tests, were then performed using a statistical package (i.e., IBM SPSS Statistics 22). The outcome of statistical testing were used to determine whether there were statistically significant changes in the mean nutrient concentrations and to formulate conclusions surrounding the potential linkage between of land cover change and water quality.

3.3.2 Land Cover Change

Remotely sensed imagery for the region was sourced from the United State Geological Survey (USGS) through the EarthExplorer Interface (USGS, 2017). Remotely sensed imagery was evaluated with the purpose of locating four images that can be utilized in land-use / land change analysis. The Landsat series of satellites was the source of imagery, specifically Landsat

5 and Landsat 8. The images utilized were acquired on June 1987, September 1997, September 2007 and September 2017 (Table 12). While it would have been ideal to have a scene from September 1987, the images available for this time were of poor quality and did not meet the cloud cover requirement of less than 10%, thus June 1987 was substituted. Following atmospheric correction for all images, both supervised and unsupervised classification was completed in the PCI Geomatica Focus application with each followed by an accuracy assessment (PCI, 2017). The USGS land-use / land cover classification system was used to maintain consistency in classes across classification of all images. The images classified via unsupervised classification yield a higher accuracy with respect to the forest class, thus they were selected for the continued analysis. The four images were then imported into ArcMap where then were reclassified as binary images (i.e., “forest” and “not forest”). These reclassified images were then evaluated using FRAGSTATS, a program used to quantify landscape fragmentation through the generation of class-based metrics, accomplished through analyzing the spatial configuration of the landscape, where spatial configuration is the “spatial character and arrangement, position or orientation of patches, within the class or landscape” (Johnson & Kasischke, 1998). The following patch metrics were analysis for each image: total (class) area, percentage of landscape, number of patches, patch density, total edge, patch area distribution mean and standard deviation. All metrics utilized were patch metrics as they are most appropriate for representing landscape configuration, despite not spatially explicit (McGarigal & Marks, 1994).

3.3.4 Final Analysis

The investigation into water quality and land cover change occurred separately and used to draw conclusion about the relationship between the two phenomena within the Carleton River system. These two analyses were undertaken with the understanding that water quality and land-use / land cover could not be directly connected through this study and thus conclusion cannot be drawn with respect to correlation. However, through comparing trends in land cover change and the significance of water quality changes, preliminary conclusions were extracted from the two conducted analyses.

3.4 Reliability/Validity/Trustworthiness

With respect to the water quality data, it is assumed the data sets used to compile the data are valid, because of repetition in the methods. This assumption is fair because the studies utilized modelled their methods after one another. For example, Sollows (2015;2016) modeled his methods after Brylinsky and Sollows (2014). Furthermore, Taylor (2009; 2010) and Brylinsky (2012a) modelled their approaches off those outlined by Nova Scotia Environment and the Nova Scotia Department of Fisheries and Oceans. Additionally, the studies utilized in this analysis either sent their samples in part or in full to independent laboratories for testing, both the ALS Laboratory in Winnipeg and the Environmental Services Laboratory of the QE II Health Services Centre in Halifax were utilized (Brylinsky, 2012a; Sollows, 2015; Sollows, 2016; Taylor, 2009; Taylor 2010). The grounding of the methods in regulatory bodies and the repetition evidenced, gives their collective nature reliability. The parameters being measured, total phosphorus, total nitrogen, total nitrite-nitrate and pH, are valid because it has been concluded that phosphorus and nitrogen are the primary nutrients of concern with respect to eutrophication, while pH is an important indicator of the aquatic ecosystems overall health (Schindler, 1974).

Remote sensing was used as it allows for the continuous measurement of land, on a regional scale, and is one of the few methods that can facilitate this analysis at low cost. Thus, its selection as a tool is valid, given the focus on detecting land cover and structure change. The medium spatial resolution of Landsat may compromise reliability in some respects, this can be counterbalanced through improved spectral resolution. Though checking the methods against the literature, they gain credibility. Recognizing that classification methods have been standardized and successfully implemented across a range of studies (Butt, Shabbir, Ahmad & Aziz, 2015; Ivits & Koch; Ivits, Koch, Blaschke, Jochum & Adler, 2005; Blaschke, 2010; Wasige, Groen, Smaling & Jetten, 2013) Lastly, all assertions and interpretations align with the data used in this study, thus asserting the confirmability of this study.

3.6 Limitations/Problems and Mitigation

3.6.1 Land Cover Analysis

A primary limitation experienced in the study was access to freely available imagery which was gathered from the USGS Earth explorer. Cloud cover prevented attaining an image from September 1987 and thus June was substituted. Furthermore, Landsat 5, which captured the 1987 images produced 30x30m pixels which made classification more challenging, as compared to the Landsat 8 imagery. The classification process was further limited as the imagery itself had to be used as a reference when performing classification, with the exception of 2017, as there was no available aerial photography available for the region. As a consequence of spatial resolution, mixed pixels limited the accuracy of classification methods. In summary, limitations surrounding water quality will become limitations of the study and those surrounding remote sensing can be accounted for through adjustments made prior to or during analysis.

3.6.2 Water Quality Analysis

The primary limitation when analyzing water quality was the existence of data gaps, that impeded the ability to conduct a uninterrupted longitudinal study. However, there are no mitigation measures that can be applied if the data does simply not exist. While the overall methods of the studies appear to be sound, some studies identified study specific limitations. For example, Brylinsky (2012b) was unable to launch a boat into Nowlands Lake in 2011 and as a result was limited to only shoreline samples within that location.

4.0 Results

4.1 Results – Forest Class Analysis

The land-use / land cover change analysis was ultimately distilled to focus on change in the 'forest' class, thus the forest acted as proxy for land cover and land-use change within the Carleton River watershed (Figure 2-5). The 'forest' class was analyzed using FRAGSTATS' patch metrics, using the 4-neighnor rule, and the following metrics were then interpreted for each 1987, 1997, 2007 and 2017: NP (Number of Patches), PD (Patch Density), CA (Total Class Area), PLAND (Percentage of Landscape), TE (Total Edge), MN (Area Mean) and SD (Area Standard Deviation). The changes in the 'forest' class and its accompanying metrics were used to draw conclusions with respect to not only landscape fragmentation, but also changes in land cover and land-use.

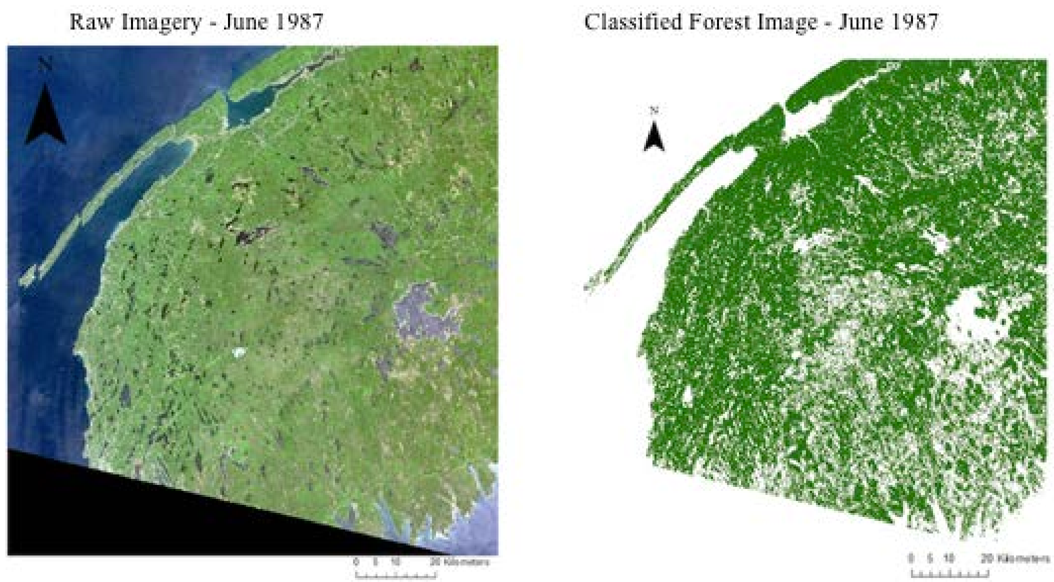

Figure 2: June 1987, comparison of original and classified imagery from Landsat Image ID: LT05_L1TP_009029_19870607_20170212_01_T1 (Path 9, Row 29), Acquisition date: 7 June 1987.

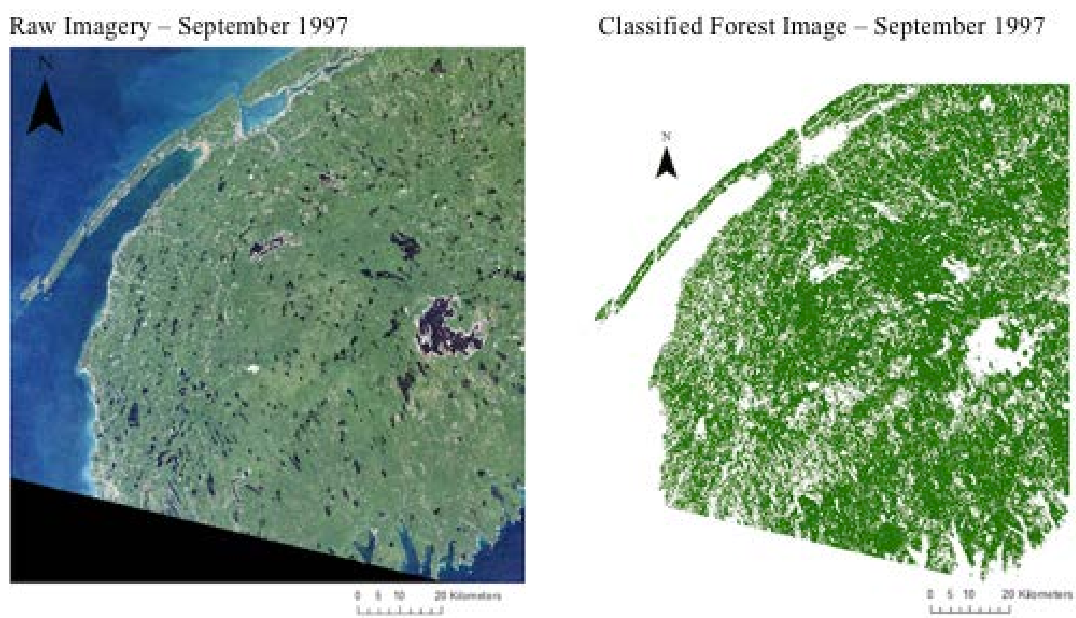

Figure 3: September 1997, comparison of original and classified imagery from Landsat Image ID: LT05_L1TP_009029_19970922_20161230_01_T1 (Path 9, Row 29), Acquisition date: 22 September 1997.

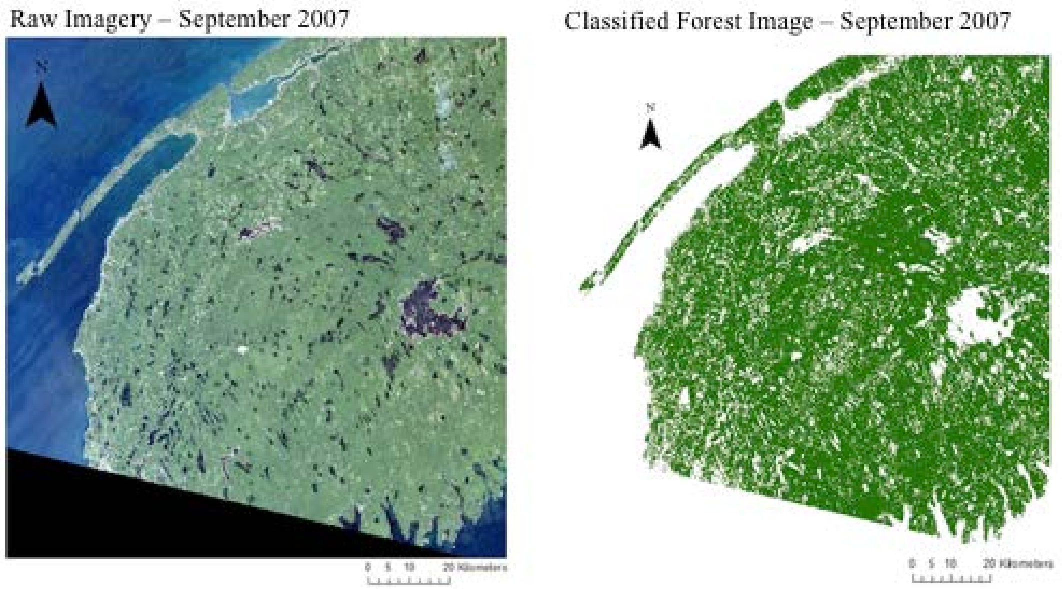

Figure 4: September 2007, comparison of original and classified imagery from Landsat Image ID: LT05_L1TP_009029_20070902_20161112_01_T1 (Path 9, Row 29), Acquisition date: 2 September 2007.

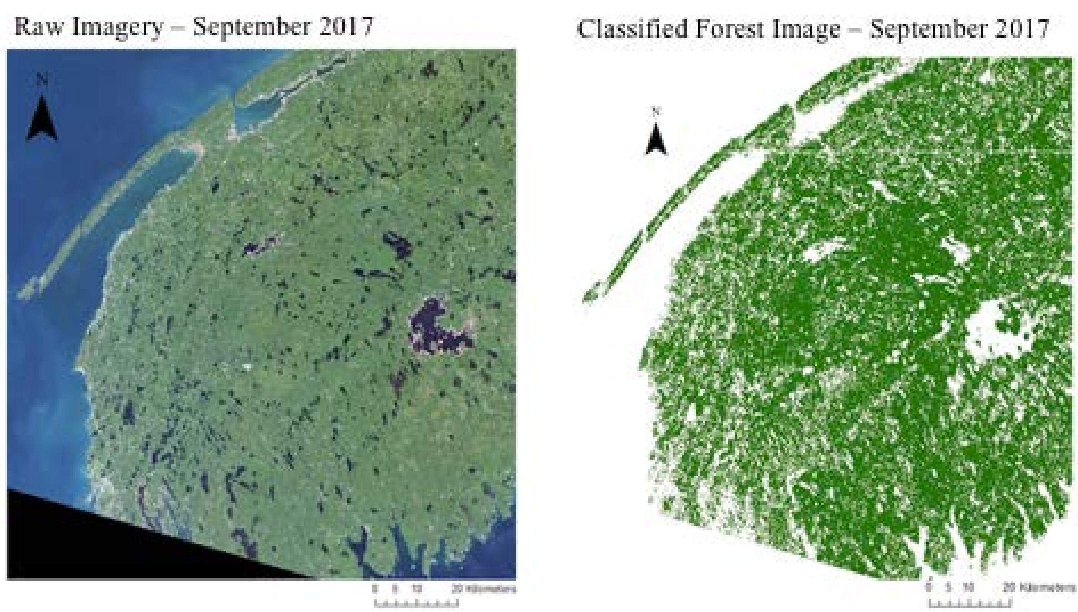

Figure 5: September 2017, comparison of original and classified imagery from Landsat Image ID: LC08_L1TP_009029_20170913_20170928_01_T1 (Path 9, Row 29), Acquisition date: 13 September 2017.

Table 1: FRAGSTATS patch metrics for the forest 'class', 1987, 1997, 2007 and 2017, using 4 neighbor rule, abbreviated from Table 13.

Date	**Type**	**NP**	**PD**	**CA (ha)**	**PLAND (%)**	**TE (m)**	**AREA_MN**	**AREA_SD**
June_87	Forest	69334	4.3938	740363.22	46.9184	82727910	10.6782	2330.0041
Sept_97	Forest	75491	4.7875	766871.37	48.6334	84232140	10.1584	2455.5050
Sept_07	Forest	37482	2.3753	825484.95	52.3128	72658719	22.0235	3764.7568
Sept_17	Forest	67402	4.2714	806532.7500	51.1117	92296380	11.9660	2388.2236

CA of the 'forest' class increases between 1987 and 2007 and then decreases between 2007 and 2017 (Figure 6). While, PLAND demonstrated an increasing trend, in which the forest has become the dominant land cover, but as with CA, PLAND decreases between 2007 and 2017 (Figure 7). While CA and PLAND appear to indicate and increasingly present 'forest' class, the trends exhibited by both metrics cannot be used solely to interpret changes in the forest class.

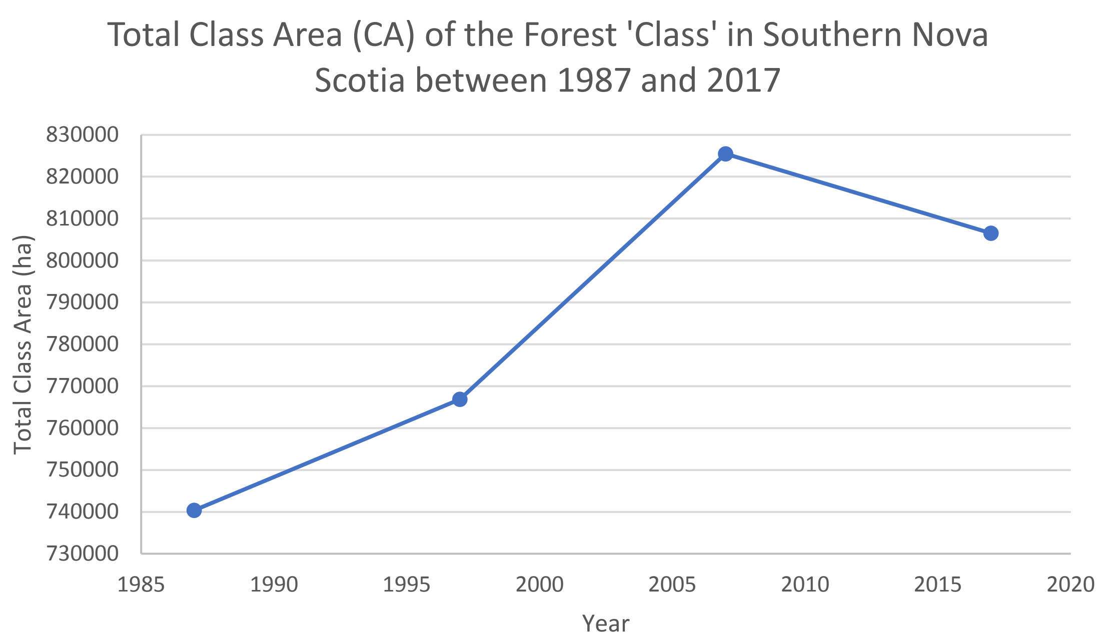

Figure 6: Total class area of the forest 'class' in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

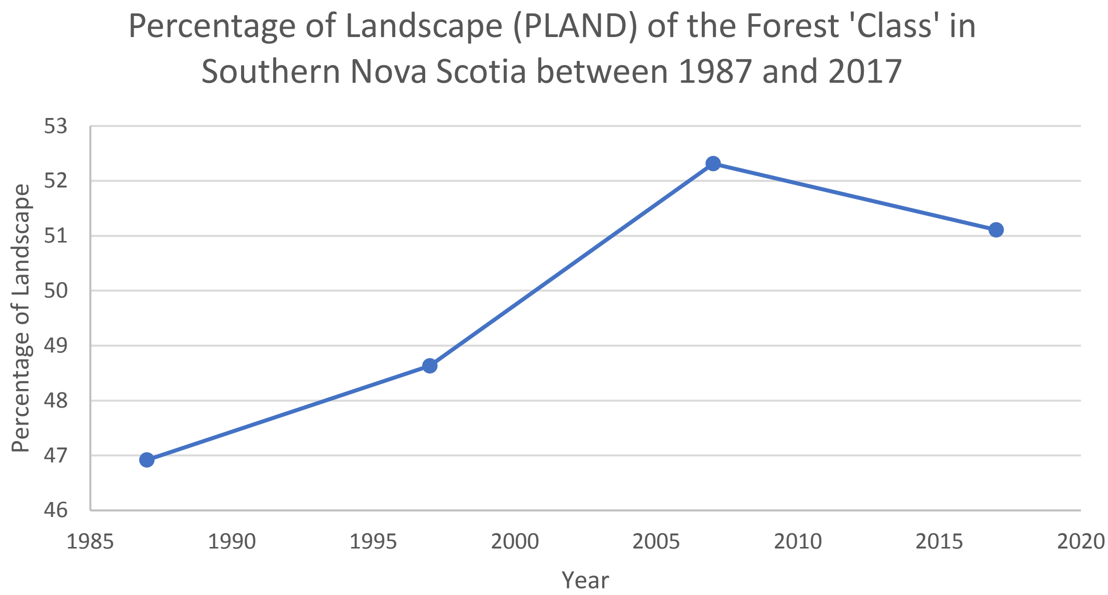

Figure 7: Percentage of landscape of the forest ‘class’ in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

NP demonstrates no clear trend, the same generalized pattern holds true for PD (Figure 8). Reiterating that PD “expresses number of patches on a per unit area basis” (UMass, No Date). Thus, the significance of PD depends entirely on the number of patches in the class and the total area of the class. While there is no pronounced trend, an increasing number of patches is indicative of fragmentation and thus change within the ‘forest’ class. Despite clear change in NP, PD remains fairly consistent, with the exception of 2007, and illustrates that while the number of patches has fluctuated their overall density has retained relatively consistent (Figure 9).

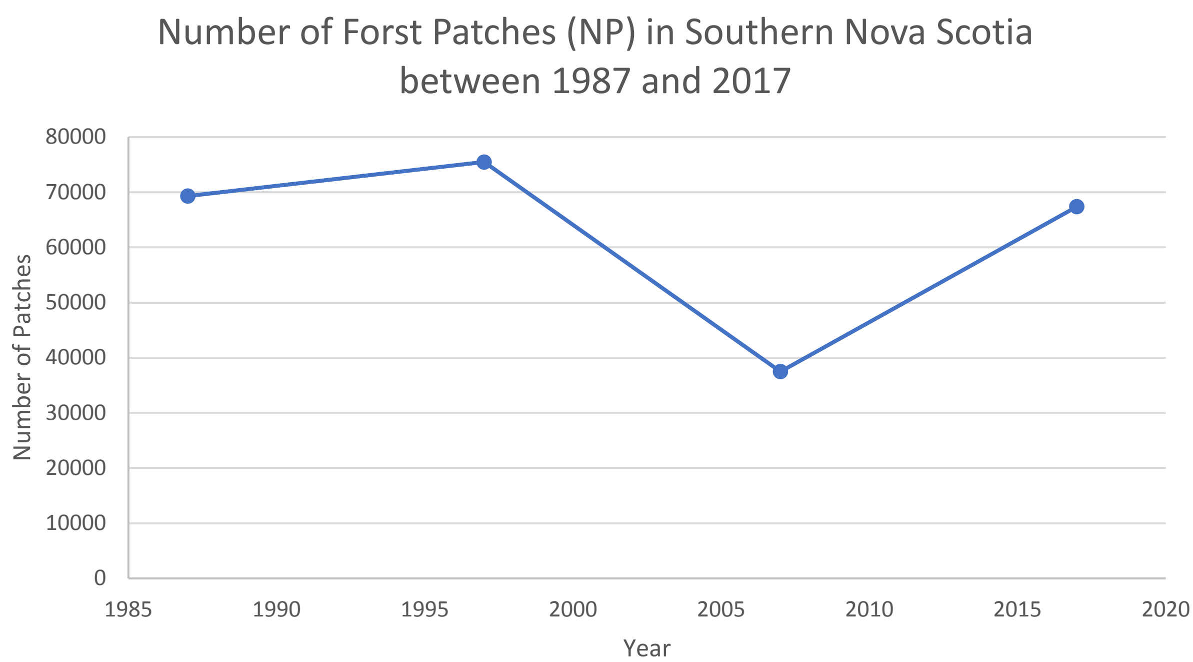

Figure 8: Number of patches of the forest ‘class’ in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

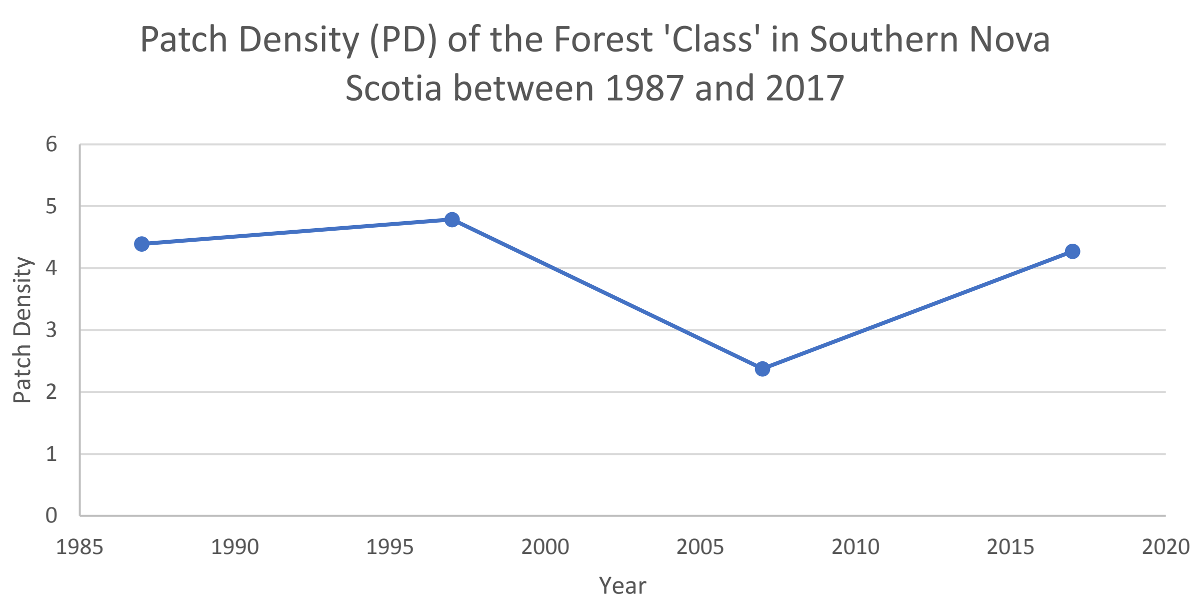

Figure 9: Patch density of the forest ‘class’ in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

TE illustrates an increase between 1987 and 1997, followed by an decrease in 2007 and increase in 2017 (Figure 10). This increase in TE is in line with the increasing NP, as the forest becomes more fragmented NP increases and so does TE.

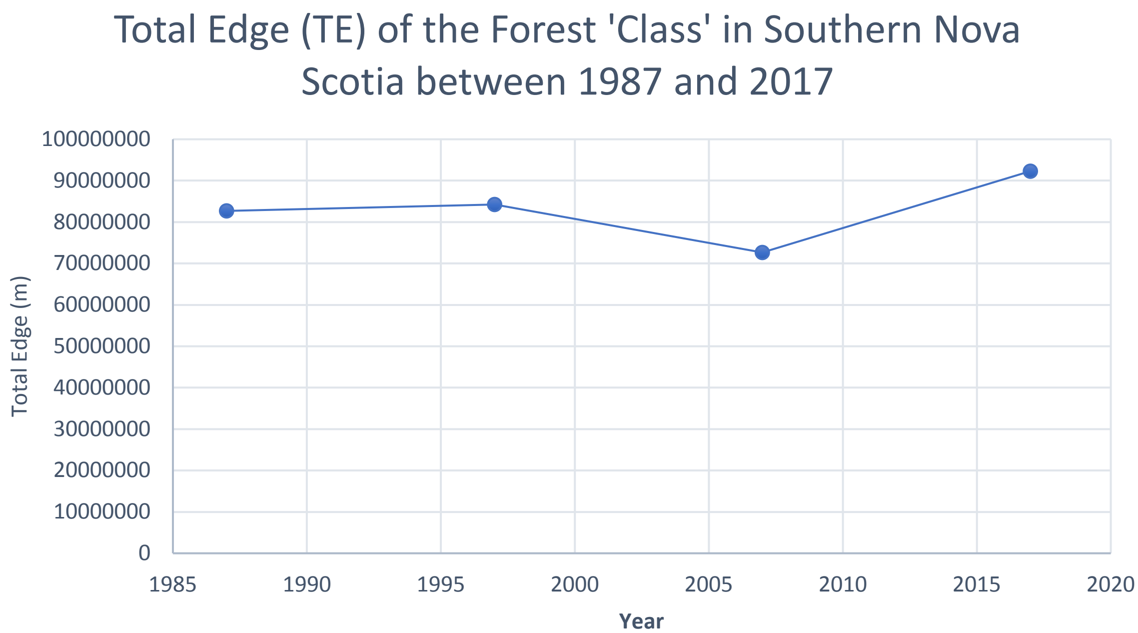

Figure 10: Total edge of the forest ‘class’ in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

MN and SD mirror each other (Figure 11, 12). MN and SD both describe the nature of patch area within the class. Noting that as the forest becomes more fragmented the MN decreases, as such the SD increases with fragmentation because patches become more variable in nature, this would not hold true if the forest was to fragment in a uniform nature.

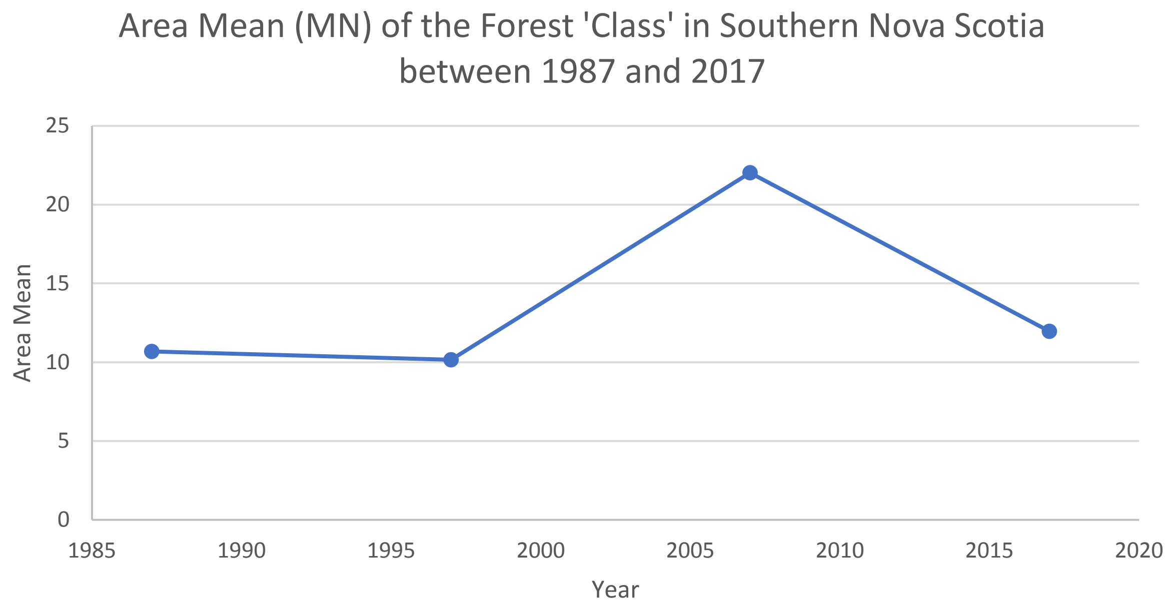

Figure 11: Area mean of the forest ‘class’ in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

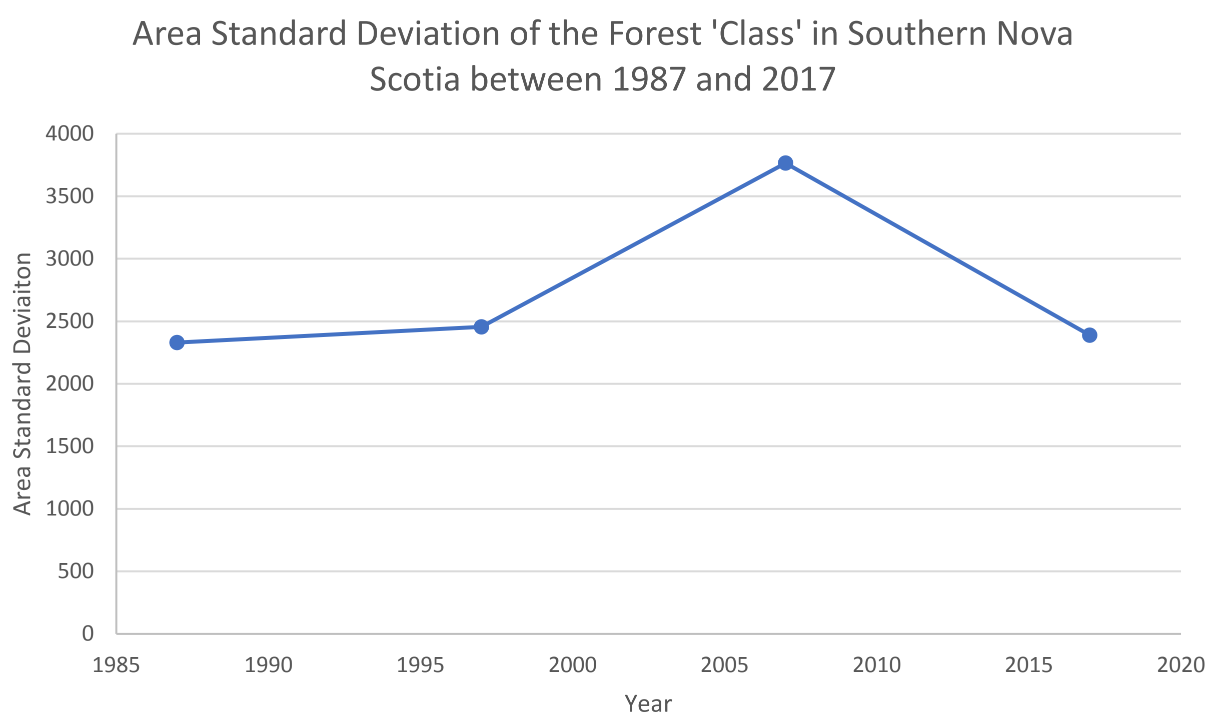

Figure 12: Area Standard Deviation of the forest ‘class’ in Southern Nova Scotia between 1987 and 2007, values were derived using FRAGSTATS (Table 1).

4.2 Results – Water Quality Secondary Analysis

Table 2: Summary of one-sample test results of water quality parameters, displayed in full in Table 4.

Summary of One-Sample Test		
Parameter	Mean	Standard Error Mean
TP	0.2240	0.05325
TN	0.5321	0.08788
NN	0.1132	0.02317
pH	6.3580	0.03870

The results of the one-sample t-test is SPSS indicates that there is significant variation within all tested water quality parameters within the Carleton River system (Table 2, 4). Indicating that with respect to TP, TN, NN and pH, the water quality within the Carleton River system has changed significantly over the past three decades. Additionally, there is evidence that means of the water quality parameters differ by location (Figure 13, 14).

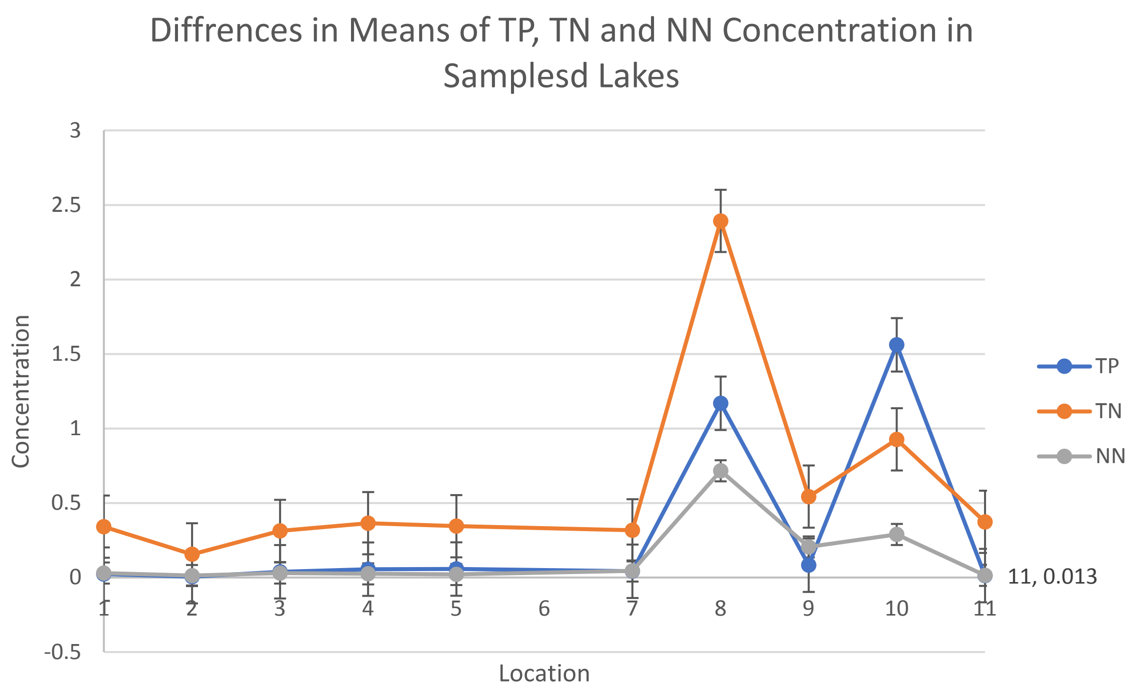

Figure 13: Differences in means of TP, TN and NN concentrations, with standard error bars, in sampled lakes, where Vaughan = 1, Sloans = 2, Fanning = 3, Ogden = 4, Parr = 5, Porcupine = 7, Placides = 8, Hourlgass = 9, Nowlans = 10 and Provost = 11. There are 10 total lakes, there is no lake 6.

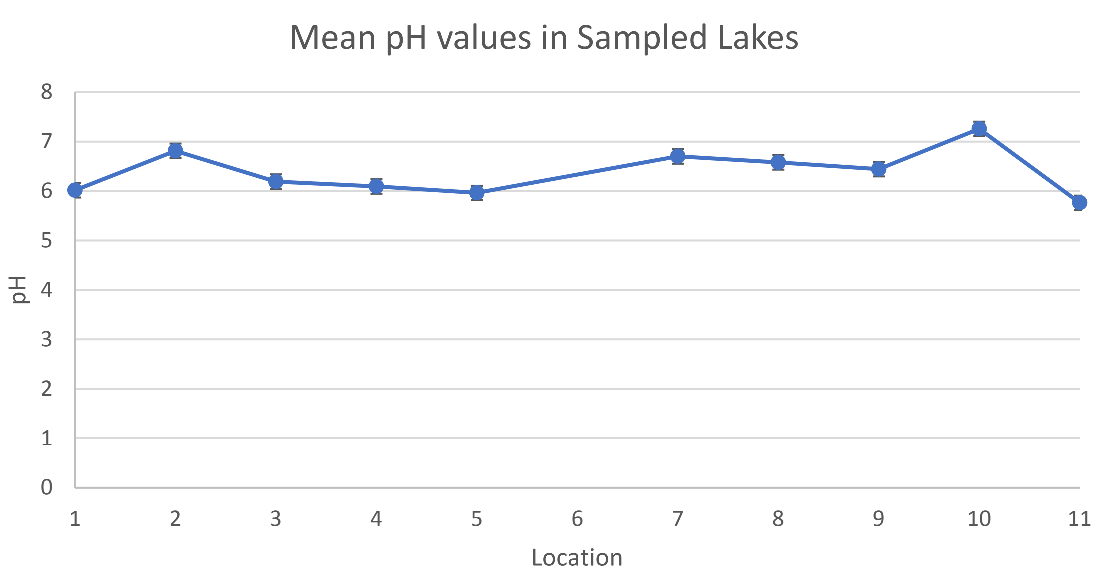

Figure 14: Differences in mean pH values, with standard error bars, in sampled lakes, where Vaughan = 1, Sloans = 2, Fanning = 3, Ogden = 4, Parr = 5, Porcupine = 7, Placides = 8, Hourlgass = 9, Nowlans = 10 and Provost = 11. There are 10 total lakes, there is no lake 6

Discussion

Despite some variation in trends all metrics analyzes can be tied to fragmentation and changes within the ‘forest’ class, either directly or indirectly. While CA and PLAND appear to indicate an expanding forest, there is still a need to account for changes in NP and additional variables, which illustrates a dynamic, changing forest that is undergoing period of fragmentation. Furthermore, SD and MN both illustrate periods in which forest patches decrease and become more varied in size, which can be indicative of fragmentation. Lastly, the generally upward trend of TE, when coupled with increasing NP, further signifies increasing fragmentation. The overarching conclusion can be drawn that the forest is not static in nature and evidence of changes in land cover and potentially changes in land-use, both of which have been previously shown to affect the water quality of neighboring aquatic systems (Baillie, Collier, & Nagels, 2005). However, while changes in land cover can be used as a proxy for changes in land-cover, it must be noted that land cover can change within the confines of static land-use. For example an agricultural land-use area will experience a change in land cover with crop growth and harvest, additionally changes in crops or agricultural methods can further alter land cover but will not change underlying land-use (Trincsi, Pham, & Tuner, 2014).

Within the context of the Carleton River watershed, there has been significant changes in the compiled water quality parameters, thus eluding to how changes in land-use have impacted water quality in the system. Recognizing, the nature of this study does not allow for a definitive conclusion to be drawn with respect to the relationship between land-use cover/change and water quality within the Carleton River system, nor can it speak to sources of nutrient loading within the system. Additionally, I has been shown that concentrations do differ by location.

The results discussed above align with the current literature, allowing for some preliminary conclusions about the relationships to be drawn. Firstly, the Carleton River System illustrates the findings of Chorus & Bartram (1999) who concluded that nitrogen and phosphorus are the primary nutrients of concern when it comes to eutrophication in freshwater bodies, evidenced by their significant increase alongside diminishing water quality within the system. Further reinforcing the findings of Salas et al. (2000) which emphasized the ability of human alterations to the landscape to cause ecological changes within freshwater environments, including but not limited to eutrophication. Additionally, providing further validation to the work of Bennett et al. (2001), S. R. Carpenter (2008b), and Matson et al. (1997) who demonstrated that land-use/cover change can drive nutrient inputs into freshwater systems, ultimately perpetuating environmental degradation.

This study speaks to the wider implications of changes in land-use / land cover and their compounding impacts on the environment. While the Carleton River system is a localized example, it illustrates the overall importance of understanding the factors within a system that lead to forest fragmentation and eutrophication. If we are able to understand how development of technology, agriculture and industry, as well as the expansion human settlement, impact local aquatic ecosystems then we can apply these understanding to a greater scale. In doing so we, as a collective, can begin to mitigate and mediate our practices in such a way that we not only understand but are in a position to reduce out impact on the environment.

5.0 Conclusion

This study provided a foundational understanding of the implications of land-use / land cover change on water quality within the Carleton River system in Southwest Western Nova Scotia. By compiling water quality data from the past thirty years and conducting a secondary analysis it was shown that there have been significant changes in total phosphorus, total nitrogen, nitrite-nitrate and pH within the system. Additionally, these changes are weakly and positively correlated to location, with the acceptation of pH. Through classifying remote sensing imagery and analyzing change within the forest class, it was concluded that there has been fluctuating changes that in many instances have resulted in fragmentation and alterations to land cover. The conclusions drawn align with the current literature and lend themselves to the conclusion that land cover/use change has impacted water quality within the Carleton River System.

Recognizing that this study is limited, in the sense that it is unable to comment on pressuring question surrounding the sources of nutrient loading within the Carleton River system, nor can it directly correlate land-use/cover change and eutrophication. Nevertheless, the findings align with current literature and allow for a strong assumption to be made, which can be built upon moving forward. Setting a foundation upon which local and regional organizations can work towards addressing environmental degradation within the Carleton River system and Nova Scotia as a whole.

In building upon this study, it would be beneficial to investigate the root causes of nutrient loading within the system, potentially focusing on industries of contention, such as mink farming, as well as less problematized but still impactful sources of pollution, such as the cottage industry and septic tanks. This would allow for environmental advocacy groups as well as policy makers to more appropriately address nutrient loading and in doing so greater explore the implications of land-use. Furthermore, it would be valuable to continue to collect water samples within the system with more regular frequency, thus allowing for more robust longitudinal studies to take place. Lastly, in the future, the land cover / land-use analysis could be narrowed to the Carleton River watershed, recognizing that the current study focused on a much larger area of interest with respect to analyzing land cover / land-use. In conclusion, this study has built upon previous regional level water quality assessments, with the addition of a land cover assessment, in order to provide a greater understanding to the environmental issues facing the Carleton River system, with the hopes it will assist advocacy groups and provide a basis for additional scientific inquiry.

6.0 References

Agriculture and Agri-Food Canada. (2014). *Riparian Area Management.* Retrieved from http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/riparian-areas/riparian-area-management/?id=1187631191985

Baillie, B. R., Collier, K. J., & Nagels, J. (2005). Effects of forest harvesting and woody debris removal on two northland streams. *New Zealand Journal of Marine and Freshwater Research, 39*(1), 1-15. doi: 10.1080/00288330.2005.9517290

Bennett, E. M., Carpenter, S. R., & Caraco, N. F. (2001). Human impact on erodible phosphorus and eutrophication: A global perspective: Increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *AIBS Bulletin, 51*(3). Retrieved from https://doi.org/10.1641/0006-3568(2001)051[0227:HIOEPA]2.0.CO;2

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS journal of photogrammetry and remote sensing*, *65*(1). Retrieved from https://doi.org/10.1016/j.isprsjprs.2009.06.004

Brylinsky, M. (2012a). *Results of the 2011 water quality survey of ten lakes located in the Carleton river watershed area of Digby and warmouth counties, Nova Scotia.* Halifax, NS: Nova Scotia Department of Environment.

Brylinsky, M. (2012b). *An assessment of the sources and magnitudes of nutrient inputs responsible for degradation of water quality in seven lakes located within the Carleton river watershed area of Digby and Yarmouth counties, nova scotia.* Wolfville, NS: Acadia Centre for Estuarine Research.

Butt, A., Shabbir, R., Ahmad, S. S., & Aziz, N. (2015). Land-use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science*, *18*(2). Retrieved from https://doi.org/10.1016/j.ejrs.2015.07.003

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, *8*(3). Retrived from https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2

Carpenter, S. R. (2008a). Phosphorus control is critical to mitigating eutrophication. *Proceedings of the National Academy of Sciences of the United States of America, 105*(32), 11039-11040. doi:10.1073/pnas.0806112105

Carpenter, S. R. (2008b). Phosphorus control is critical to mitigating eutrophication. *Proceedings of the National Academy of Sciences of the United States of America, 105*(32), 11039-11040. doi:10.1073/pnas.0806112105

Chorus, I., & Bartram, J. (Ed.). (1999). *Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management*. isbn: 0-419-23930-8

Costa, M. H., Botta, A., & Cardille, J. A. (2003). Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. *Journal of Hydrology*, *283*(1-4). Retrived from https://doi.org/10.1016/S0022-1694(03)00267-1

David Suzuki Foundation. (2011). *The impacts of the mink industry on freshwater lakes in nova scotia: An overview of concerns*. Retrieved from https://www.furfreealliance.com/wp-content/uploads/2018/02/2011-Mink-Industry-and-Lakes-in-Nova-Scotia.pdf

Dennis, J. (1986). Phosphorus export from a low-density residential watershed and an adjacent forest watershed. *Lake and Reservoir Management*, *2 (1)*, 401-407. doi: 10.1080/07438148609354665

Environment Canada. (2004). *Ecosystem health, science-based solution, Canadian guidance framework for the management of phosphorus in freshwater systems.* (No. 1-8). Ottawa, ON: Environment Canada/National Guidelines and Standards Office.

Environmental Protection Agency, Republic of Ireland (EPA, Ireland). (2018). *Integrated Catchment Management.* Retrieved from http://www.epa.ie/water/watmg/icm/

Fierro, P., Bertrán, C., Tapia, J., Hauenstein, E., Peña-Cortés, F., Vergara, C., . . . Vargas-Chacoff, L. (2017). Effects of local land-use on riparian vegetation, water quality, and the functional organization of macroinvertebrate assemblages. *Science of the Total Environment*, *609*, 724-734. doi:10.1016/j.scitotenv.2017.07.197

Foley, J. A., Defries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., . . . Snyder, P. K. (2005). Global consequences of land-use. *Science (New York, N.Y.), 309*(5734), 570-574. doi:309/5734/570

Hart, M. R., Quin, B. F., & Nguyen, M. (2004). Phosphorus runoff from agricultural land and direct fertilizer effects. *Journal of Environmental Quality*, *33*(6). Retrived from http://ezproxy.library.dal.ca/login?url=https://search.proquest.com/docview/197407208?accountid=10406

Howarth, R., & Ramakrishna, K. (2005). Nutrient management. In Etchevers, J., & Tiessen, H. (Ed.), *Ecosystems and human well-being: Policy responses* (pp. 295 - 311). Washington, DC: Island Press. Retrieved from https://www.millenniumassessment.org/documents/document.314.aspx.pdf

Ierodiaconou, D., Laurenson, L., Leblanc, M., Stagnitti, F., Duff, G., Salzman, S., & Versace, V. (2005). The consequences of land-use change on nutrient exports: A regional scale assessment in south-west Victoria, Australia. *Journal of Environmental Management, 74*(4), 305-316. doi: :10.1016/j.jenvman.2004.09.010

Ivits, E., & Koch, B. (2002, June). Object-oriented remote sensing tools for biodiversity assessment: A European approach. In *Proceedings of the 22nd EARSeL Symposium, Prague, Czech Republic* (pp. 4-6). isbn: 90-77017-71-2

Ivits, E., Koch, B., Blaschke, T., Jochum, M., & Adler, P. (2005). Landscape structure assessment with image grey-values and object-based classification at three spatial resolutions. *International Journal of Remote Sensing*, *26*(14). Retrived from https://doi.org/10.1080/01431160500057798

Johnson, R. D., & Kasischke, E. S. (1998). Change vector analysis: a technique for the multispectral monitoring of land cover and condition. *International Journal of Remote Sensing*, *19*(3). Retrieved from https://doi.org/10.1080/014311698216062

Kandemir, T., Schuster, M. E., Senyshyn, A., Behrens, M., & Schlögl, R. (2013). The Haber–Bosch process revisited: on the real structure and stability of “ammonia iron” under working conditions. *Angewandte Chemie International Edition*, *52*(48). Retrived from https://www.researchgate.net/profile/Timur_Kandemir/publication/263246467_anie_201305812_sm_miscellaneous_information/links/0c96053a4216843730000000.pdf

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., ... & George, P. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global environmental change*, *11*(4), 261-269. isbn: 0959-3780

Lavelle, P., Dugdale, R., & Scholes, R. (2005). Nutrient cycling. *Current states & trends assessment* (pp. 331-353). Washington, D.C.: Island Press.

Loveland, T., Mahmood, R., Patel-Weynand, T., Karstensen, K., Beckendorf, K., Bliss, N., & Carleton, A. (2012). National climate assessment technical report on the impacts of climate and land-use and land cover change. *US Geological Survey Open-File Report*, *1155*, 87. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.278.3639&rep=rep1&type=pdf

Matson, P. A., Parton, W. J., Power, A. G., & Swift, M. J. (1997). Agricultural intensification and ecosystem properties. *Science (New York, N.Y.), 277*(5325), 504-509. doi: 10.1126/science.277.5325.504

McGarigal, K., & Marks, B. J. (1994). *FRAGSTATS: Spatial pattern analysis program for quantifying landscape change*. Corvallis(OR): Forest Science Department, Oregon State University.

Medel, B. (2012, June 11). Mink industry booms despite pollution concerns. *The Chronicle Herald*. Retrieved from http://thechronicleherald.ca/novascotia/105779-mink-industry-booms-despite-pollution-concerns

Moore, S. K., Trainer, V. L., Mantua, N. J., Parker, M. S., Laws, E. A., Backer, L. C., & Fleming, L. E. (2008, November). Impacts of climate variability and future climate change on harmful algal blooms and human health. In *Environmental Health* (Vol. 7, No. 2, p. S4). BioMed Central.

Nova Scotia Environment. (2011). *Blue-green algae.* Nova Scotia Environment. Retrieved from https://novascotia.ca/nse/water/docs/BlueGreenAlgae.pdf

PCI Geomatics. (2017). *Geomatica object analyst – new object based image analysis module.* Retrieved from http://www.pcigeomatics.com/pdf/geomatica/techspecs/Geomatica-Object-Analyst-Flyer.pdf

Ryan, R. J., & Boufadel, M.C. (2007). Lateral and longitudinal variation of hypothetic exchange in a piedmont stream pool. *Environmental sicence & technology, 41*(12). 4221-4226. doi: 10.1021/es061603z

Rahikainen, M., Hoviniemi, K. M., Mäntyniemi, S., Vanhatalo, J., Helle, I., Lehtiniemi, M., ... & Kuikka, S. (2017). Impacts of eutrophication and oil spills on the Gulf of Finland herring stock. *Canadian Journal of Fisheries and Aquatic Sciences*, *74*(8). Retrieved from https://doi.org/10.1139/cjfas-2016-0108

Richards, S., Paterson, E., Withers, P. J., & Stutter, M. (2016). Septic tank discharges as multi-pollutant hotspots in catchments. *Science of the Total Environment*, *542*. Retrieved from https://doi.org/10.1016/j.scitotenv.2015.10.160

Sala, O. E., Chapin, F. S.,3rd, Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., . . . Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *Science*, *287*(5459), 1770-1774. doi:8204

Schindler, D. W. (1974). Eutrophication and recovery in experimental lakes: Implications for lake management. *Science*, *184*(4139), 897-899. doi:184/4139/897

Schindler, D. W. (1977). Evolution of phosphorus limitation in lakes. *Science*, *195*(4275), 260-262. doi:195/4275/260

Schindler, D. W., Hecky, R. E., Findlay, D. L., Stainton, M. P., Parker, B. R., Paterson, M. J., . . . Kasian, S. E. (2008). Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(32), 11254-11258. doi:10.1073/pnas.0805108105

Sollows, J. D. (2015). *Results of the 2014 water quality survey of eleven lakes in Yarmouth and Digby Counties* Tusket River Environmental Protection Association.

Sollows, J. D. (2016). *Result of the 2015 water quality survey of fourteen lakes in warmouth and digby counties*. Yarmouth (NS): Technical Adivisory Sub-Committee - Tusket River Environmental Protection Association.

Strain, P. M., & Hargrave, B. T. (2005). Salmon aquaculture, nutrient fluxes and ecosystem processes in southwestern New Brunswick. In *Environmental Effects of Marine Finfish Aquaculture* (pp. 29-57). Springer, Berlin, Heidelberg. doi: 10.1007/b136003

Taylor, D. (2009). *A water quality survey of nine lakes in the Carleton river watershed area, Yarmouth County, Nova Scotia.* Halifax, NS: Water & Wastewater Branch, Nova Scotia Environment. Retrieved from http://www.yarmouth.org/magazine/pollution_in_the_tusket/pdf/FinalRpt_Yarmouth-area-lakes-report-with-appendices-INA-(1).pdf

Taylor, D. (2010). *A water quality survey of ten lakes in the Carleton river watershed area of Yarmouth and Digby Counties, Nova Scotia*. Halifax, NS: Water & Wastewater Branch, Nova Scotia Environment.

Trincsi, K., Pham, T., & Turner, S. (2014). Mapping mountain diversity: ethnic minorities and land use land cover changes in Vietnam's borderlands. *Land Use Policy, 41*. Retrieved from https://doi.org/10.1016/j.landusepol.2014.06.022

Turner, B., Meyer, W. B., & Skole, D. L. (1994). Global land-use/land-cover change: Towards an integrated study. *Ambio.Stockholm, 23*(1). Retrieved from http://www.jstor.org/stable/4314168

United States Environmental Protection Agency (EPA). (2015). *Mississippi River/Gulf of Mexico watershed nutrient task force 2015 report to congress.* Retrieved from https://www.epa.gov/sites/production/files/2015-10/documents/htf_report_to_congress_final_-_10.1.15.pdf

United States Geological Survey (USGS). (2017). *EarthExplorer.* Retrieved from https://earthexplorer.usgs.gov/

Wasige, J. E., Groen, T. A., Smaling, E., & Jetten, V. (2013). Monitoring basin-scale land cover changes in Kagera Basin of Lake Victoria using ancillary data and remote sensing. *International Journal of Applied Earth Observation and Geoinformation, 21*. Retrieved from https://doi.org/10.1016/j.jag.2012.08.005

Water and Rivers Commission, Western Australia. (2000, July). *Water notes, advisory notes for land managers on river and wetland restoration.* Retrieved from https://www.water.wa.gov.au/__data/assets/pdf_file/0017/3158/11444.pdf

Zarkadas, I., Dontis, G., Pilidis, G., & Sarigiannis, D. (2016). Exploring the potential of fur farming wastes and byproducts as substrates to anaerobic digestion process. *Renewable Energy, 96*. Retrived from https://doi.org/10.1016/j.renene.2016.03.056

7.0 Appendix A: SPSS Output: Descriptive Statistics & One-Sample Statistics

Table 3: Descriptive statistics, generated in SPSS, of water quality data reported in Table 14.

Water Quality Descriptive Statistics

	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Location	286	10.00	1.00	11.00	1524.00	5.3287	.19712	3.33356	11.113
Total Phosphorus	283	8.70	.00	8.70	63.38	.2240	.05325	.89584	.803
Total Nitrogen	137	11.30	.03	11.33	73.32	.5351	.08788	1.02861	1.058
Nitrite-Nitrate	226	3.39	.01	3.40	25.59	.1132	.02317	.34833	.121
pH	247	4.20	4.30	8.50	1570.42	6.3580	.03870	.60820	.370
Valid N (listwise)	77								

Table 4: Descriptive statistics (continued), generated in SPSS, of water quality data reported in Table 14.

Report

Location		TP	TN	NN	pH
1.00	Mean	.0227	.3414	.0302	6.0155
	N	30	14	25	31
	Std. Deviation	.01909	.14728	.02279	.75725
2.00	Mean	.0056	.1554	.0133	6.8155
	N	46	24	38	40
	Std. Deviation	.00203	.03162	.01209	.20088
3.00	Mean	.0386	.3125	.0304	6.1928
	N	40	16	33	39
	Std. Deviation	.04878	.13665	.03064	.31858
4.00	Mean	.0561	.3646	.0246	6.0929
	N	27	13	21	24
	Std. Deviation	.06094	.16081	.02055	.30813
5.00	Mean	.0569	.3442	.0203	5.9624

	N	27	12	21	21
	Std. Deviation	.03422	.16752	.02096	.47592
7.00	Mean	.0418	.3167	.0436	6.7000
	N	20	12	16	16
	Std. Deviation	.06553	.09198	.03668	.27568
8.00	Mean	1.1690	2.3927	.7161	6.5800
	N	24	11	18	20
	Std. Deviation	1.27794	3.08272	.49109	.37219
9.00	Mean	.0826	.5431	.2051	6.4426
	N	25	13	19	19
	Std. Deviation	.09466	.17143	.45640	.48641
10.00	Mean	1.5611	.9270	.2888	7.2588
	N	17	10	16	16
	Std. Deviation	2.82549	.32496	.84781	.59731
11.00	Mean	.0130	.3738	.0146	5.7624
	N	27	12	19	21
	Std. Deviation	.00581	.16171	.00976	.58289
Total	Mean	.2240	.5351	.1132	6.3580
	N	283	137	226	247
	Std. Deviation	.89584	1.02861	.34833	.60820

Table 5 One-sample T-test statistics, generated in SPSS, of water quality data reported in Table 14.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Total Phosphorus	283	.2240	.89584	.05325
Total Nitrogen	137	.5351	1.02861	.08788
Nitrite-Nitrate	226	.1132	.34833	.02317
pH	247	6.3580	.60820	.03870
Location	286	5.3287	3.33356	.19712

Table 6: One-sample T-test results, generated in SPSS, of water quality data reported in Table 14.

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Total Phosphorus	4.205	282	.000	.22395	.1191	.3288
Total Nitrogen	6.090	136	.000	.53515	.3614	.7089
Nitrite-Nitrate	4.887	225	.000	.11323	.0676	.1589
pH	164.295	246	.000	6.35798	6.2818	6.4342
Location	27.033	285	.000	5.32867	4.9407	5.7167

7.2 Appendix B: SPSS Frequency Output

Table 7: Location frequency output of water quality data reported in Table 14. Where Vaughan = 1, Sloans = 2, Fanning = 3, Ogden = 4, Parr = 5, Porcupine = 7, Placides = 8, Hourlgass = 9, Nowlans = 10 and Provost = 11. There are 10 total lakes, there is no lake 6.

Location

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	31	10.8	10.8	10.8
	2.00	46	16.1	16.1	26.9
	3.00	40	14.0	14.0	40.9
	4.00	27	9.4	9.4	50.3
	5.00	27	9.4	9.4	59.8
	7.00	22	7.7	7.7	67.5
	8.00	24	8.4	8.4	75.9
	9.00	25	8.7	8.7	84.6
	10.00	17	5.9	5.9	90.6
	11.00	27	9.4	9.4	100.0
	Total	286	100.0	100.0	

Table 8: Total Nitrogen frequency output, generated in SPSS, of water quality data reported in Table 14.

Total Nitrogen

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.03	2	.7	1.5	1.5
	.05	1	.3	.7	2.2
	.11	1	.3	.7	2.9
	.12	2	.7	1.5	4.4
	.13	2	.7	1.5	5.8
	.14	5	1.7	3.6	9.5
	.15	5	1.7	3.6	13.1
	.16	3	1.0	2.2	15.3
	.17	4	1.4	2.9	18.2
	.18	3	1.0	2.2	20.4
	.19	4	1.4	2.9	23.4
	.21	4	1.4	2.9	26.3
	.22	4	1.4	2.9	29.2
	.23	1	.3	.7	29.9
	.24	5	1.7	3.6	33.6
	.25	4	1.4	2.9	36.5
	.27	4	1.4	2.9	39.4
	.28	3	1.0	2.2	41.6
	.29	3	1.0	2.2	43.8
	.30	1	.3	.7	44.5
	.31	1	.3	.7	45.3
	.32	1	.3	.7	46.0
	.33	1	.3	.7	46.7
	.34	3	1.0	2.2	48.9
	.35	4	1.4	2.9	51.8
	.36	1	.3	.7	52.6
	.39	2	.7	1.5	54.0
	.40	8	2.8	5.8	59.9
	.41	4	1.4	2.9	62.8
	.42	2	.7	1.5	64.2
	.44	2	.7	1.5	65.7

	.45	5	1.7	3.6	69.3
	.46	2	.7	1.5	70.8
	.47	1	.3	.7	71.5
	.48	2	.7	1.5	73.0
	.49	1	.3	.7	73.7
	.50	1	.3	.7	74.5
	.52	1	.3	.7	75.2
	.53	1	.3	.7	75.9
	.56	1	.3	.7	76.6
	.56	4	1.4	2.9	79.6
	.57	5	1.7	3.6	83.2
	.61	1	.3	.7	83.9
	.62	1	.3	.7	84.7
	.64	1	.3	.7	85.4
	.68	1	.3	.7	86.1
	.73	1	.3	.7	86.9
	.77	1	.3	.7	87.6
	.78	1	.3	.7	88.3
	.80	1	.3	.7	89.1
	.86	3	1.0	2.2	91.2
	1.01	1	.3	.7	92.0
	1.17	1	.3	.7	92.7
	1.23	1	.3	.7	93.4
	1.24	1	.3	.7	94.2
	1.34	1	.3	.7	94.9
	1.59	1	.3	.7	95.6
	1.69	2	.7	1.5	97.1
	1.83	1	.3	.7	97.8
	2.80	1	.3	.7	98.5
	2.95	1	.3	.7	99.3
	11.33	1	.3	.7	100.0
	Total	137	47.9	100.0	
Missing	System	149	52.1		
Total		286	100.0		

Table 9: Nitrite-Nitrate frequency output, generated in SPSS, of water quality data reported in Table 14.

Nitrite-Nitrate

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.01	55	19.2	24.3	24.3
	.01	81	28.3	35.8	60.2
	.01	1	.3	.4	60.6
	.02	9	3.1	4.0	64.6
	.03	10	3.5	4.4	69.0
	.04	7	2.4	3.1	72.1
	.05	5	1.7	2.2	74.3
	.06	23	8.0	10.2	84.5
	.07	5	1.7	2.2	86.7
	.08	3	1.0	1.3	88.1
	.10	2	.7	.9	88.9
	.14	1	.3	.4	89.4
	.16	1	.3	.4	89.8
	.21	2	.7	.9	90.7
	.22	1	.3	.4	91.2
	.27	1	.3	.4	91.6
	.29	1	.3	.4	92.0
	.35	1	.3	.4	92.5
	.47	1	.3	.4	92.9
	.51	1	.3	.4	93.4
	.54	2	.7	.9	94.2
	.58	1	.3	.4	94.7
	.85	1	.3	.4	95.1
	.95	1	.3	.4	95.6
	1.10	4	1.4	1.8	97.3
	1.25	1	.3	.4	97.8
	1.26	1	.3	.4	98.2
	1.28	1	.3	.4	98.7
	1.31	1	.3	.4	99.1
	1.90	1	.3	.4	99.6
	3.40	1	.3	.4	100.0
	Total	226	79.0	100.0	

Missing	System	60	21.0		
Total		286	100.0		

Table 10: pH frequency output, generated in SPSS, of water quality data reported in Table 14.

pH

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4.30	2	.7	.8	.8
	4.60	1	.3	.4	1.2
	4.70	2	.7	.8	2.0
	4.80	1	.3	.4	2.4
	4.90	1	.3	.4	2.8
	5.00	1	.3	.4	3.2
	5.10	1	.3	.4	3.6
	5.20	2	.7	.8	4.5
	5.30	1	.3	.4	4.9
	5.40	4	1.4	1.6	6.5
	5.50	4	1.4	1.6	8.1
	5.53	1	.3	.4	8.5
	5.57	1	.3	.4	8.9
	5.60	4	1.4	1.6	10.5
	5.70	1	.3	.4	10.9
	5.71	1	.3	.4	11.3
	5.78	1	.3	.4	11.7
	5.80	5	1.7	2.0	13.8
	5.81	1	.3	.4	14.2
	5.86	1	.3	.4	14.6
	5.88	1	.3	.4	15.0
	5.90	15	5.2	6.1	21.1
	5.93	1	.3	.4	21.5
	5.96	1	.3	.4	21.9
	6.00	9	3.1	3.6	25.5
	6.01	1	.3	.4	25.9
	6.07	2	.7	.8	26.7
	6.10	12	4.2	4.9	31.6
	6.11	2	.7	.8	32.4
	6.19	1	.3	.4	32.8
	6.20	29	10.1	11.7	44.5
	6.23	1	.3	.4	44.9
	6.24	1	.3	.4	45.3

	6.26	1	.3	.4	45.7
	6.30	14	4.9	5.7	51.4
	6.31	1	.3	.4	51.8
	6.32	1	.3	.4	52.2
	6.40	11	3.8	4.5	56.7
	6.50	9	3.1	3.6	60.3
	6.52	1	.3	.4	60.7
	6.53	1	.3	.4	61.1
	6.60	15	5.2	6.1	67.2
	6.70	4	1.4	1.6	68.8
	6.77	1	.3	.4	69.2

Table 11: Total phosphorus frequency output, generated in SPSS, of water quality data reported in Table 14.

Total Phosphorus

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	5	1.7	1.8	1.8
	.00	14	4.9	4.9	6.7
	.01	19	6.6	6.7	13.4
	.01	12	4.2	4.2	17.7
	.01	7	2.4	2.5	20.1
	.01	3	1.0	1.1	21.2
	.01	5	1.7	1.8	23.0
	.01	6	2.1	2.1	25.1
	.01	13	4.5	4.6	29.7
	.01	10	3.5	3.5	33.2
	.01	10	3.5	3.5	36.7
	.02	6	2.1	2.1	38.9
	.02	12	4.2	4.2	43.1
	.02	3	1.0	1.1	44.2
	.02	6	2.1	2.1	46.3
	.02	6	2.1	2.1	48.4
	.02	3	1.0	1.1	49.5
	.02	7	2.4	2.5	51.9
	.02	4	1.4	1.4	53.4
	.02	5	1.7	1.8	55.1
	.03	2	.7	.7	55.8
	.03	1	.3	.4	56.2
	.03	4	1.4	1.4	57.6
	.03	1	.3	.4	58.0
	.03	5	1.7	1.8	59.7
	.03	4	1.4	1.4	61.1
	.04	1	.3	.4	61.5
	.04	1	.3	.4	61.8
	.04	1	.3	.4	62.2
	.05	4	1.4	1.4	63.6
	.05	2	.7	.7	64.3
	.05	1	.3	.4	64.7

	.05	3	1.0	1.1	65.7
	.05	1	.3	.4	66.1
	.05	1	.3	.4	66.4
	.05	2	.7	.7	67.1
	.06	6	2.1	2.1	69.3
	.06	1	.3	.4	69.6
	.06	1	.3	.4	70.0
	.06	2	.7	.7	70.7
	.06	1	.3	.4	71.0
	.06	1	.3	.4	71.4
	.06	1	.3	.4	71.7
	.06	1	.3	.4	72.1
	.07	1	.3	.4	72.4
	.07	2	.7	.7	73.1
	.07	3	1.0	1.1	74.2
	.07	1	.3	.4	74.6
	.08	3	1.0	1.1	75.6
	.08	4	1.4	1.4	77.0
	.08	2	.7	.7	77.7
	.08	2	.7	.7	78.4
	.08	1	.3	.4	78.8
	.09	2	.7	.7	79.5
	.09	1	.3	.4	79.9
	.10	1	.3	.4	80.2
	.10	5	1.7	1.8	82.0
	.10	1	.3	.4	82.3
	.10	1	.3	.4	82.7
	.11	1	.3	.4	83.0
	.11	1	.3	.4	83.4
	.11	1	.3	.4	83.7
	.17	1	.3	.4	84.1
	.20	1	.3	.4	84.5
	.22	1	.3	.4	84.8
	.23	1	.3	.4	85.2
	.24	1	.3	.4	85.5
	.26	1	.3	.4	85.9
	.30	1	.3	.4	86.2
	.34	1	.3	.4	86.6

	.35	1	.3	.4	86.9
	.37	1	.3	.4	87.3
	.38	2	.7	.7	88.0
	.39	2	.7	.7	88.7
	.40	1	.3	.4	89.0
	.42	2	.7	.7	89.8
	.46	1	.3	.4	90.1
	.50	1	.3	.4	90.5
	.59	1	.3	.4	90.8
	.61	2	.7	.7	91.5
	.63	1	.3	.4	91.9
	.66	1	.3	.4	92.2
	.70	1	.3	.4	92.6
	.70	2	.7	.7	93.3
	.71	1	.3	.4	93.6
	.72	2	.7	.7	94.3
	.74	2	.7	.7	95.1
	.79	1	.3	.4	95.4
	.81	1	.3	.4	95.8
	.82	2	.7	.7	96.5
	.83	1	.3	.4	96.8
	.94	1	.3	.4	97.2
	.96	2	.7	.7	97.9
	2.10	1	.3	.4	98.2
	5.20	2	.7	.7	98.9
	5.40	1	.3	.4	99.3
	7.90	1	.3	.4	99.6
	8.70	1	.3	.4	100.0
	Total	283	99.0	100.0	
Missing	System	3	1.0		
Total		286	100.0		

7.3 Appendix C: Landsat Imagery Information

Table 12: Satellite imagery descriptions of imagery used in forest class analysis.

Satellite Imagery Descriptions	
1987	**ID:**LT05_L1TP_009029_19870607_20170212_01_T1 **Acquisition Date:**07-JUN-87 **Path:**9 **Row:**29 **Sensor:** Landstat 5 TM
1997	**ID:**LT05_L1TP_009029_19970922_20161230_01_T1 **Acquisition Date:**22-SEP-97 **Path:**9 **Row:**29 **Sensor:** Landstat 5 TM
2007	**ID:**LT05_L1TP_009029_20070902_20161112_01_T1 **Acquisition Date:**02-SEP-07 **Path:**9 **Row:**29 **Sensor:** Landsat 5 TM
2017	**ID:**LC08_L1TP_009029_20170913_20170928_01_T1 **Acquisition Date:**13-SEP-17 **Path:**9 **Row:**29 **Sensor:** Landsat 8 OLI/TIRS

7.4 Appendix D: FRAGSTATS Metrics

Table 13: FRAGSTATS patch metrics for the forest class, 1987, 1997, 2007 and 2017, using 4 neighbor rule.

Date	**Type**	**NP**	**PD**	**CA**	**PLAND**	**TE**	**AREA_MN**	**AREA_SD**
June_87	Not_Forest	148639	9.4196	837616.05	53.0816	82727910	6.6352	1599.5661
June_87	Forest	69334	4.3938	740363.22	46.9184	82727910	10.6782	2330.0041
Sept_97	Not_Forest	124574	7.9002	809970.21	51.3666	84232140	6.5019	1501.0498
Sept_97	Forest	75491	4.7875	766871.37	48.6334	84232140	10.1584	2455.5050
Sept_07	Not_Forest	177180	11.2283	75249.32	47.6872	72658710	4.2471	1277.5507
Sept_07	Forest	37482	2.3753	825484.95	52.3128	72658719	22.0235	3764.7568
Sept_17	Not_Forest	203373	12.8882	771446.5200	48.8883	92296380	3.7933	1069.0137
Sept_17	Forest	67402	4.2714	806532.7500	51.1117	92296380	11.9660	2388.2236

7.5 Appendix E: Raw Water Quality Data

Table 14: Raw water quality data compiled from Brylinsky (2012a), Sollows (2015, 2016), and Taylor (2009,2010) and used for statistical analysis.

Source (Author, Year)	Location - Lake (Watershed)	Sample Date	TP (mg/L)	TN (mg/L)	N-N (mg/L)	pH Units
Taylor, 2009	Hourglass (Carleton)	9/1/83	0.012	0.29	<0.01	5.81
Taylor, 2009	Hourglass (Carleton)	9/1/83	0.011	0.41	<0.01	6.11
Taylor, 2009	Hourglass (Carleton)	9/1/83	0.045	0.46	0.27	6.11
Taylor, 2009	Parr (Carleton)	7/3/86	0.006	0.23	<0.01	5.78
Taylor, 2009	Ogden (Carleton)	7/9/86	0.004	0.19	<0.01	5.9
Taylor, 2009	Fanning (Carleton)	7/10/86	0.004	0.17	<0.01	5.53
Taylor, 2009	Provst (Sissiboo)	9/26/83	0.003	0.57	<0.01	5.88
Taylor, 2009	Provst (Sissiboo)	9/23/83	0.003	0.19	<0.01	5.57
Taylor, 2009	Nowlans (Meteghan)	9/27/83	0.006	0.56	<0.01	6.23
Taylor, 2009	Nowlans (Meteghan)	9/27/83	0.025	0.78	<0.01	6.01
Taylor, 2009	Parr (Carleton)	10/29/02	0.012	0.18	<0.01	6.3
Taylor, 2009	Hourglass (Carleton)	8/27/08	0.051	0.47	<0.01	7.2
Taylor, 2009	Hourglass (Carleton)	8/14/08	0.069	0.57	0.03	6.2
Taylor, 2009	Placides (Carleton)	8/27/08	0.39	0.39	<0.01	7.6
Taylor, 2009	Placides (Carleton)	8/14/08	0.74	1.69	0.35	6.5
Taylor, 2009	Placides (Carleton)	8/14/08	5.2	2.95	0.02	6.3
Taylor, 2009	Porcupine (Carleton)	8/28/08	0.009	0.21	<0.01	7.2
Taylor, 2009	Porcupine (Carleton)	8/13/08	0.015	0.22	<0.01	6.6
Taylor, 2009	Porcupine (Carleton)	8/13/08	0.021	0.4	<0.01	6.3

Taylor, 2009	Parr (Carleton)	9/4/08	0.021	0.27	<0.01	6.9
Taylor, 2009	Parr (Carleton)	8/14/08	0.033	0.27	<0.01	6.2
Taylor, 2009	Ogden (Carleton)	9/4/08	0.017	0.27	<0.01	6.3
Taylor, 2009	Ogden (Carleton)	8/15/08	0.017	0.25	<0.01	6.1
Taylor, 2009	Ogden (Carleton)	8/15/08	0.018	0.24	0.03	5.8
Taylor, 2009	Ogden (Carleton)	8/15/08	0.097	0.8	<0.01	5.9
Taylor, 2009	Fanning (Carleton)	8/28/08	0.009	0.24	<0.01	6.1
Taylor, 2009	Fanning (Carleton)	10/15/08	0.014	0.24	<0.01	6.6
Taylor, 2009	Fanning (Carleton)	8/13/08	0.011	0.21	<0.01	6.4
Taylor, 2009	Fanning (Carleton)	8/13/08	0.023	0.19	<0.01	6.3
Taylor, 2009	Fanning (Carleton)	8/13/08	0.097	0.62	<0.01	6.5
Taylor, 2009	Vaughan (Carleton)	9/5/08	0.007	0.21	<0.01	7.2
Taylor, 2009	Vaughan (Carleton)	9/5/08	0.005	0.17	<0.01	6.3
Taylor, 2009	Vaughan (Carleton)	9/5/08	0.012	0.45	<0.01	6.3
Taylor, 2009	Vaughan (Carleton)	9/5/08	0.045	0.73	<0.01	6.3
Taylor, 2009	Provst (Sissiboo)	8/27/08	0.011	0.36	<0.01	6.2
Taylor, 2009	Provst (Sissiboo)	8/15/08	0.011	0.45	<0.01	6.1
Taylor, 2009	Nowlans (Meteghan)	8/28/08	0.35	1.59	<0.01	7
Taylor, 2009	Nowlans (Meteghan)	8/28/08	0.34	0.86	<0.01	7.5
Taylor, 2009	Nowlans (Meteghan)	8/28/08	0.46	1.17	<0.01	7.5
Taylor, 2009	Nowlans (Meteghan)	10/15/08	0.23	1.24	<0.01	7.6
Taylor, 2009	Nowlans (Meteghan)	8/14/08	0.04	1.01	<0.01	6.5
Taylor, 2010	Hourglass (Carleton)	10/20/09	0.078	0.86	0.21	6.2

Taylor, 2010	Hourglass (Carleton)	10/20/09	0.079	0.86	0.22	6.2
Taylor, 2010	Placides (Carleton)	10/21/09	0.72	11.33	1.1	6.5
Taylor, 2010	Placides (Carleton)	10/21/09	0.7	2.8	1.1	6.4
Taylor, 2010	Porcupine (Carleton)	10/27/09	0.034	0.45	0.06	6.6
Taylor, 2010	Porcupine (Carleton)	10/27/09	0.033	0.4	0.07	6.7
Taylor, 2010	Porcupine (Carleton)	10/27/09	0.035	0.41	0.07	6.6
Taylor, 2010	Parr (Carleton)	10/22/09	0.098	0.56	0.07	5.4
Taylor, 2010	Parr (Carleton)	10/22/09	0.095	0.56	0.07	5.4
Taylor, 2010	Ogden (Carleton)	10/22/09	0.066	0.46	0.06	5.8
Taylor, 2010	Ogden (Carleton)	10/22/09	0.067	0.48	0.06	5.9
Taylor, 2010	Fanning (Carleton)	10/13/09	0.056	0.4	0.06	5.9
Taylor, 2010	Fanning (Carleton)	10/13/09	0.06	0.4	0.06	5.9
Taylor, 2010	Fanning (Carleton)	10/13/09	0.056	0.44	0.06	6
Taylor, 2010	Sloans (Carleton)	9/10/09	0.005	0.18	<0.01	6.9
Taylor, 2010	Sloans (Carleton)	9/10/09	0.007	0.19	0.06	6.8
Taylor, 2010	Sloans (Carleton)	9/10/09	<0.005	0.15	<0.01	6.8
Taylor, 2010	Sloans (Carleton)	9/10/09	<0.005	0.15	0.03	6.7
Taylor, 2010	Sloans (Carleton)	9/10/09	0.005	0.16	<0.01	6.8
Taylor, 2010	Sloans (Carleton)	9/10/09	0.006	0.11	<0.01	
Taylor, 2010	Sloans (Carleton)	9/10/09	<0.005	0.15	<0.01	6.9
Taylor, 2010	Sloans (Carleton)	9/10/09	<0.005	0.16	<0.01	6.8
Taylor, 2010	Sloans (Carleton)	9/10/09	0.005	0.12	<0.01	
Taylor, 2010	Sloans (Carleton)	9/10/09	0.006	0.22	<0.01	6.9

Taylor, 2010	Sloans (Carleton)	11/5/09	0.012	0.25	0.01	7
Taylor, 2010	Sloans (Carleton)	11/5/09	<0.005	0.14	<0.01	6.8
Taylor, 2010	Sloans (Carleton)	11/5/09	<0.005	0.14	<0.01	6.8
Taylor, 2010	Sloans (Carleton)	11/5/09	<0.005	0.14	<0.01	6.9
Taylor, 2010	Sloans (Carleton)	11/5/09	<0.005	0.17	<0.01	
Taylor, 2010	Sloans (Carleton)	11/5/09	0.006	0.14	<0.01	6.9
Taylor, 2010	Sloans (Carleton)	11/5/09	0.006	0.15	<0.01	6.8
Taylor, 2010	Sloans (Carleton)	11/5/09	0.006	0.15	<0.01	
Taylor, 2010	Vaughan (Carleton)	10/28/09	0.033	0.4	0.06	6.2
Taylor, 2010	Vaughan (Carleton)	10/28/09	0.034	0.39	0.06	6.2
Taylor, 2010	Vaughan (Carleton)	10/28/09	0.015	0.4	0.02	4.7
Taylor, 2010	Vaughan (Carleton)	10/28/09	0.023	0.42	0.03	4.9
Taylor, 2010	Provst (Sissiboo)	10/27/09	0.02	0.31	<0.01	5.9
Taylor, 2010	Provst (Sissiboo)	10/27/09	0.02	0.28	<0.01	5.6
Taylor, 2010	Nowlans (Meteghan)	10/15/09	0.38	0.68	<0.01	7.3
Taylor, 2010	Nowlans (Meteghan)	10/15/09	0.38	0.61	<0.01	7.3
Brylinsky, 2012	Hourglass (Carleton)	9/26/10	0.05		0.21	
Brylinsky, 2012	Hourglass (Carleton)	9/26/10	0.063		0.01	6.8
Brylinsky, 2012	Hourglass (Carleton)	9/26/10	0.05		0.01	6.8
Brylinsky, 2012	Hourglass (Carleton)	9/26/10	0.37		1.9	7.6
Brylinsky, 2012	Hourglass (Carleton)	9/26/10	0.043		0.03	6.9
Brylinsky, 2012	Hourglass (Carleton)	8/14/11	0.045		0.04	
Brylinsky, 2012	Hourglass (Carleton)	8/14/11	0.39		0.01	

Brylinsky, 2012	Hourglass (Carleton)	8/14/11	0.023		0.85	
Brylinsky, 2012	Hourglass (Carleton)	8/14/11	0.022		0.01	
Brylinsky, 2012	Hourglass (Carleton)	8/14/11	0.087		0.05	
Brylinsky, 2012	Placides (Carleton)	9/27/10	0.82		0.47	6.9
Brylinsky, 2012	Placides (Carleton)	9/27/10	0.83		0.54	6.9
Brylinsky, 2012	Placides (Carleton)	9/27/10	0.94		1.31	6.8
Brylinsky, 2012	Placides (Carleton)	9/27/10	0.71		0.29	6.9
Brylinsky, 2012	Placides (Carleton)	8/23/11	0.96		0.58	
Brylinsky, 2012	Placides (Carleton)	8/23/11	2.1		0.16	
Brylinsky, 2012	Porcupine (Carleton)	9/27/10	0.021		0.01	6.8
Brylinsky, 2012	Porcupine (Carleton)	9/27/10			0.01	6.8
Brylinsky, 2012	Porcupine (Carleton)	9/27/10	0.11		0.1	6.9
Brylinsky, 2012	Porcupine (Carleton)	9/27/10	0.019		0.01	6.9
Brylinsky, 2012	Porcupine (Carleton)	8/15/11	0.014		0.01	
Brylinsky, 2012	Porcupine (Carleton)	8/15/11			0.08	
Brylinsky, 2012	Porcupine (Carleton)	8/15/11	0.3		0.08	
Brylinsky, 2012	Porcupine (Carleton)	8/15/11	0.014		0.01	
Brylinsky, 2012	Parr (Carleton)	9/27/10	0.061		0.01	6.2
Brylinsky, 2012	Parr (Carleton)	9/27/10	0.099		0.01	6.1
Brylinsky, 2012	Parr (Carleton)	9/27/10	0.012		0.01	5.9
Brylinsky, 2012	Parr (Carleton)	9/28/10	0.057		0.04	6.6
Brylinsky, 2012	Parr (Carleton)	8/25/11	0.054		0.01	6.2
Brylinsky, 2012	Parr (Carleton)	8/25/11	0.075		0.01	

Brylinsky, 2012	Parr (Carleton)	8/25/11	0.076		0.01	
Brylinsky, 2012	Parr (Carleton)	8/25/11	0.097		0.03	
Brylinsky, 2012	Parr (Carleton)	8/25/11	0.076		0.01	
Brylinsky, 2012	Parr (Carleton)	8/25/11	0.012		0.01	
Brylinsky, 2012	Parr (Carleton)	8/25/11	0.062		0.01	
Brylinsky, 2012	Ogden (Carleton)	9/28/10	0.029		0.05	6.3
Brylinsky, 2012	Ogden (Carleton)	9/28/10	0.26		0.01	7
Brylinsky, 2012	Ogden (Carleton)	9/28/10	0.054		0.01	6.2
Brylinsky, 2012	Ogden (Carleton)	9/28/10	0.029		0.06	6.2
Brylinsky, 2012	Ogden (Carleton)	8/25/11	0.22		0.01	
Brylinsky, 2012	Ogden (Carleton)	8/25/11	0.094		0.02	
Brylinsky, 2012	Ogden (Carleton)	8/25/11	0.025		0.01	
Brylinsky, 2012	Fanning (Carleton)	9/30/10	0.019		0.05	6.4
Brylinsky, 2012	Fanning (Carleton)	9/30/10	0.021		0.06	6.4
Brylinsky, 2012	Fanning (Carleton)	10/1/10	0.24		0.14	6.6
Brylinsky, 2012	Fanning (Carleton)	10/1/10	0.008		0.01	6.7
Brylinsky, 2012	Fanning (Carleton)	10/1/10	0.005		0.01	6.6
Brylinsky, 2012	Fanning (Carleton)	10/1/10	0.019		0.07	6.5
Brylinsky, 2012	Fanning (Carleton)	8/18/11	0.023		0.01	6.2
Brylinsky, 2012	Fanning (Carleton)	8/18/11	0.082		0.01	
Brylinsky, 2012	Fanning (Carleton)	8/18/11	0.018		0.01	6.1
Brylinsky, 2012	Fanning (Carleton)	8/18/11	0.007		0.01	6.8
Brylinsky, 2012	Fanning (Carleton)	8/18/11	0.005		0.01	6.6

Brylinsky, 2012	Fanning (Carleton)	8/18/11	0.015		0.01	6.2
Brylinsky, 2012	Sloans (Carleton)	7/4/02	0.003		0.01	6.9
Brylinsky, 2012	Sloans (Carleton)	7/4/02	0.003		0.01	6.8
Brylinsky, 2012	Sloans (Carleton)	8/28/02	0.01		0.01	6.8
Brylinsky, 2012	Sloans (Carleton)	8/28/02	0.01		0.01	6.8
Brylinsky, 2012	Sloans (Carleton)	10/23/02	0.005		0.01	6.6
Brylinsky, 2012	Sloans (Carleton)	10/23/02	0.005		0.01	6.6
Brylinsky, 2012	Sloans (Carleton)	10/1/10	0.009		0.01	7
Brylinsky, 2012	Sloans (Carleton)	10/1/10	0.007		0.01	6.9
Brylinsky, 2012	Sloans (Carleton)	10/1/10	0.005		0.01	7
Brylinsky, 2012	Sloans (Carleton)	10/1/10	0.005		0.01	6.8
Brylinsky, 2012	Sloans (Carleton)	10/1/10	0.007		0.01	6.8
Brylinsky, 2012	Sloans (Carleton)	10/1/10	0.005		0.01	7
Brylinsky, 2012	Sloans (Carleton)	8/16/11	0.005		0.01	7
Brylinsky, 2012	Sloans (Carleton)	8/16/11	0.01		0.01	6.9
Brylinsky, 2012	Sloans (Carleton)	8/16/11	0.005		0.01	6.9
Brylinsky, 2012	Vaughan (Carleton)	8/1/79			0.05	6
Brylinsky, 2012	Vaughan (Carleton)	10/1/10	0.018		0.04	6.2
Brylinsky, 2012	Vaughan (Carleton)	10/1/10	0.078		0.01	7.1
Brylinsky, 2012	Vaughan (Carleton)	10/1/10	0.019		0.04	5.5
Brylinsky, 2012	Vaughan (Carleton)	10/1/10	0.014		0.01	6.5
Brylinsky, 2012	Vaughan (Carleton)	10/1/10	0.017		0.04	5.2
Brylinsky, 2012	Vaughan (Carleton)	8/17/11	0.01		0.01	6.2

Brylinsky, 2012	Vaughan (Carleton)	8/17/11	0.087		0.01	72
Brylinsky, 2012	Vaughan (Carleton)	8/17/11	0.009		0.01	6.6
Brylinsky, 2012	Vaughan (Carleton)	8/17/11	0.008		0.01	5.2
Brylinsky, 2012	Vaughan (Carleton)	8/17/11	0.011		0.01	5.3
Brylinsky, 2012	Provst (Sissiboo)	10/1/10	0.016		0.04	6
Brylinsky, 2012	Provst (Sissiboo)	10/1/10	0.016		0.04	6
Brylinsky, 2012	Provst (Sissiboo)	10/1/10	0.015			6.6
Brylinsky, 2012	Provst (Sissiboo)	10/1/10	0.015			6.6
Brylinsky, 2012	Provst (Sissiboo)	8/15/11	0.011		0.01	
Brylinsky, 2012	Provst (Sissiboo)	8/15/11	0.016		0.01	
Brylinsky, 2012	Provst (Sissiboo)	8/15/11	0.011		0.01	
Brylinsky, 2012	Provst (Sissiboo)	8/15/11	0.016		0.01	
Brylinsky, 2012	Nowlans (Meteghan)	9/26/10	0.42		0.01	8.5
Brylinsky, 2012	Nowlans (Meteghan)	9/26/10	8.7		0.54	7.5
Brylinsky, 2012	Nowlans (Meteghan)	9/26/10	0.42		0.01	7.6
Brylinsky, 2012	Nowlans (Meteghan)	8/22/11	0.59		0.01	7.4
Brylinsky, 2012	Nowlans (Meteghan)	8/22/11	7.9		0.51	7.5
Brylinsky, 2012	Hourglass (Carleton)	10/20/09	0.17		0.01	5.7
Brylinsky, 2012	Hourglass (Carleton)	10/20/09	0.049		0.01	6.4
Brylinsky, 2012	Placides (Carleton)	8/14/08	5.2		0.02	6.3
Brylinsky, 2012	Placides (Carleton)	10/21/09	0.63		1.25	6
Brylinsky, 2012	Placides (Carleton)	10/21/09	0.61		1.26	6.1
Brylinsky, 2012	Placides (Carleton)	10/21/09	0.72		1.1	6.5

Brylinsky, 2012	Placides (Carleton)	10/21/09	0.7		1.1	6.4
Brylinsky, 2012	Placides (Carleton)	10/21/09	0.61		1.28	6.2
Brylinsky, 2012	Placides (Carleton)	10/21/09	0.66		0.95	6.3
Brylinsky, 2012	Porcupine (Carleton)	10/27/09	0.079		0.1	6
Brylinsky, 2012	Porcupine (Carleton)	10/27/09	0.031		0.06	6.6
Brylinsky, 2012	Parr (Carleton)	10/22/09	0.018		0.01	6.2
Brylinsky, 2012	Parr (Carleton)	10/22/09	0.011		0.01	5.1
Brylinsky, 2012	Parr (Carleton)	10/22/09	0.016		0.01	5
Brylinsky, 2012	Parr (Carleton)	10/22/09	0.076		0.06	5.5
Brylinsky, 2012	Ogden (Carleton)	7/3/02	0.014		0.01	6.1
Brylinsky, 2012	Ogden (Carleton)	8/15/08	0.018		0.03	5.8
Brylinsky, 2012	Ogden (Carleton)	8/15/08	0.097		0.01	5.9
Brylinsky, 2012	Ogden (Carleton)	8/15/08	0.014		0.01	6.1
Brylinsky, 2012	Ogden (Carleton)	10/22/09	0.018		0.03	5.8
Brylinsky, 2012	Ogden (Carleton)	10/22/09	0.097		0.01	5.9
Brylinsky, 2012	Ogden (Carleton)	10/22/09	0.076		0.06	5.5
Brylinsky, 2012	Fanning (Carleton)	7/11/86	0.004		0.01	5.5
Brylinsky, 2012	Fanning (Carleton)	7/3/02	0.011		0.02	5.9
Brylinsky, 2012	Fanning (Carleton)	8/28/02	0.008		0.01	6.2
Brylinsky, 2012	Fanning (Carleton)	8/23/02	0.012		0.01	6.1
Brylinsky, 2012	Fanning (Carleton)	8/17/08	0.011		0.01	6.4
Brylinsky, 2012	Fanning (Carleton)	9/13/09	0.056		0.06	5.9
Brylinsky, 2012	Fanning (Carleton)	9/13/09	0.06		0.06	5.9

Brylinsky, 2012	Fanning (Carleton)	9/13/09	0.056		0.06	5.6
Brylinsky, 2012	Fanning (Carleton)	10/14/09	0.064		0.06	5.9
Brylinsky, 2012	Fanning (Carleton)	10/14/09	0.2		0.01	6.3
Brylinsky, 2012	Fanning (Carleton)	10/14/09	0.007		0.01	6.4
Brylinsky, 2012	Fanning (Carleton)	10/14/09	0.059		0.05	6
Brylinsky, 2012	Sloans (Carleton)	7/3/86	0.003		0.01	5.8
Brylinsky, 2012	Sloans (Carleton)	9/13/09	0.005		0.01	6.9
Brylinsky, 2012	Sloans (Carleton)	9/13/09	0.006			
Brylinsky, 2012	Sloans (Carleton)	9/13/09	0.007		0.06	6.8
Brylinsky, 2012	Sloans (Carleton)	9/13/09	0.005		0.01	6.8
Brylinsky, 2012	Sloans (Carleton)	9/13/09	0.006			
Brylinsky, 2012	Sloans (Carleton)	9/13/09	0.005		0.03	6.7
Brylinsky, 2012	Vaughan (Carleton)	10/28/09	0.033		0.06	6.2
Brylinsky, 2012	Vaughan (Carleton)	10/28/09	0.034		0.06	6.2
Brylinsky, 2012	Vaughan (Carleton)	10/28/09	0.015		0.02	4.7
Brylinsky, 2012	Vaughan (Carleton)	10/28/09	0.034		0.06	6.2
Brylinsky, 2012	Vaughan (Carleton)	10/28/09	0.014		0.08	4.6
Brylinsky, 2012	Vaughan (Carleton)	10/28/09	0.022		0.03	4.8
Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.006		0.02	5.9
Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.006		0.02	5.6
Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.006		0.02	5.6
Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.005		0.014	4.3
Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.014		0.01	4.3

Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.016		0.01	5.4
Brylinsky, 2012	Provst (Sissiboo)	10/27/09	0.016		0.01	5.4
Brylinsky, 2012	Nowlans (Meteghan)	10/15/09	5.4		3.4	7.5
Brylinsky, 2012	Nowlans (Meteghan)	10/15/09	0.4		0.06	7.2
Sollows, 2015	Hourglass (Carleton)	8/13/08	0.069	0.57	6.2	
Sollows, 2015	Hourglass (Carleton)	9/25/10	0.05	0.35	6.8	
Sollows, 2015	Hourglass (Carleton)	8/13/11	0.046	0.64	6.8	
Sollows, 2015	Hourglass (Carleton)	8/12/13	0.056	0.56	6.07	
Sollows, 2015	Hourglass (Carleton)	8/18/14	0.067	0.45	6.31	
Sollows, 2015	Placides (Carleton)	8/13/09	0.74	1.69	6.5	
Sollows, 2015	Placides (Carleton)	9/26/10	0.82	1.23	6.9	
Sollows, 2015	Placides (Carleton)	8/22/11	0.96	1.83	6.8	
Sollows, 2015	Placides (Carleton)	8/6/13	0.792	1.34	6.8	
Sollows, 2015	Placides (Carleton)	8/25/14	0.806	0.57		
Sollows, 2015	Porcupine (Carleton)	8/12/08	0.012	0.22	6.6	
Sollows, 2015	Porcupine (Carleton)	9/26/10	0.021	0.25	6.8	
Sollows, 2015	Porcupine (Carleton)	8/14/11	0.014	0.3	6.9	
Sollows, 2015	Porcupine (Carleton)	8/6/13	0.021	0.42	6.9	
Sollows, 2015	Porcupine (Carleton)	8/25/14	0.016	0.28		
Sollows, 2015	Parr (Carleton)	8/14/08	0.033	0.27	6.2	
Sollows, 2015	Parr (Carleton)	8/24/10	0.075	0.03	6.2	
Sollows, 2015	Parr (Carleton)	9/26/10	0.071	0.33	6.2	
Sollows, 2015	Parr (Carleton)	8/12/13	0.105	0.53	5.71	

Sollows, 2015	Parr (Carleton)	8/25/14	0.111	0.49	5.86	
Sollows, 2015	Ogden (Carleton)	8/14/08	0.014	0.25	6.1	
Sollows, 2015	Ogden (Carleton)	9/27/10	0.029	0.35	6.3	
Sollows, 2015	Ogden (Carleton)	8/24/11	0.022	0.28	6.1	
Sollows, 2015	Ogden (Carleton)	8/6/11	0.052	0.41	6.4	
Sollows, 2015	Ogden (Carleton)	8/24/11	0.046	0.44	6.3	
Sollows, 2015	Fanning (Carleton)	8/16/08	0.011	0.21	6.4	
Sollows, 2015	Fanning (Carleton)	9/12/09	0.056	0.4	5.9	
Sollows, 2015	Fanning (Carleton)	9/29/10	0.021	0.35	6.4	
Sollows, 2015	Fanning (Carleton)	8/17/11	0.023	0.05	6.2	
Sollows, 2015	Fanning (Carleton)	8/11/13	0.045	0.4	5.93	
Sollows, 2015	Fanning (Carleton)	8/24/14	0.027	0.34	6.07	
Sollows, 2015	Sloans (Carleton)	9/12/09	0.005	0.18	6.9	
Sollows, 2015	Sloans (Carleton)	9/20/10	0.009	0.12	7	
Sollows, 2015	Sloans (Carleton)	8/15/11	0.005	0.13	7	
Sollows, 2015	Sloans (Carleton)	8/11/13	0.004	0.14	6.77	
Sollows, 2015	Sloans (Carleton)	8/24/14	0.004	0.13	6.85	
Sollows, 2015	Vaughan (Carleton)	9/4/08	0.012	0.17	7.2	
Sollows, 2015	Vaughan (Carleton)	9/30/10	0.019	0.34	6.2	
Sollows, 2015	Vaughan (Carleton)	8/16/11	0.01	0.22	6.2	
Sollows, 2015	Vaughan (Carleton)	8/13/13	0.02	0.29	6.24	
Sollows, 2015	Vaughan (Carleton)	8/18/14	0.012	0.35	6.32	
Sollows, 2015	Provst (Sissiboo)	8/14/09	0.011	0.45	6.1	

Sollows, 2015	Provst (Sissiboo)	9/30/10	0.016	0.29	6	
Sollows, 2015	Provst (Sissiboo)	8/14/11	0.011	0.03	6	
Sollows, 2015	Provst (Sissiboo)	8/13/13	0.016	0.48	5.96	
Sollows, 2015	Provst (Sissiboo)	8/24/14	0.016	0.52		
Sollows, 2016	Hourglass (Carleton)	8/17/15	0.069	0.57	6.2	
Sollows, 2016	Placides (Carleton)	8/26/15	0.698	0.5		
Sollows, 2016	Porcupine (Carleton)	8/26/15	0.016	0.24		
Sollows, 2016	Parr (Carleton)	8/20/15	0.075	0.41	6.26	
Sollows, 2016	Ogden (Carleton)	8/20/15	0.022	0.32	6.53	
Sollows, 2016	Fanning (Carleton)	8/16/15	0.019	0.34	6.19	
Sollows, 2016	Sloans (Carleton)	8/16/15	0.004	0.16	6.5	
Sollows, 2016	Vaughan (Carleton)	8/18/15	0.01	0.24	6.52	
Sollows, 2016	Provst (Sissiboo)	8/25/15	0.029	0.555		
Sollows, 2016	Nowlans (Meteghan)	8/26/15	0.497	0.77		

7.6 Appendix F: Accuracy Matrix and Error Confusion Matrix for Supervised and Unsupervised Classifications

Table 15: Accuracy matrix of 1987 supervised classification of Landsat Image ID: LT05_L1TP_009029_19870607_20170212_01_T1 (Path 9, Row 29), Acquisition date: 7 June 1987.

Accuracy Statistics

Overall Accuracy : 47.000% 95% Confidence Interval (39.833% 54.167%)
Overall Kappa Statistic: 0.352 Overall Kappa Variance : 0.002

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Class-00	0.000%	(-16.667% 16.667%)	0.000%	(-2.273% 2.273%)	-0.0152
Water	77.500%	(63.309% 91.691%)	91.176%	(80.172% 102.181%)	0.8897
Agricultu	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000
Range_Lan	28.261%	(14.162% 42.360%)	46.429%	(26.170% 66.687%)	0.3043
Forest_La	47.826%	(35.315% 60.337%)	64.706%	(50.610% 78.802%)	0.4612
Barren_La	57.143%	(37.027% 77.259%)	53.333%	(33.814% 72.852%)	0.4574
Urban_Bui	7.143%	(-9.919% 24.205%)	7.143%	(-9.919% 24.205%)	0.0015

Table 16: Error confusion matrix for 1987 supervised classification of Landsat Image ID: LT05_L1TP_009029_19870607_20170212_01_T1 (Path 9, Row 29), Acquisition date: 7 June 1987.

Error (Confusion) Matrix

Classified Data	Reference Data: Class-00	Water	Agricultu	Range_Lan	Forest_La	Barren_La
Class-00	0	9	0	3	6	3
Water	3	31	0	0	0	0
Agricultu	0	0	0	3	7	4
Range_Lan	0	0	0	13	14	0
Forest_La	0	0	0	16	33	1
Barren_La	0	0	0	6	5	16
Urban_Bui	0	0	0	5	4	4
Unknown	0	0	0	0	0	0
Totals	3	40	0	46	69	28

Table 17: Accuracy matrix of 1987 unsupervised classification of Landsat Image ID: LT05_L1TP_009029_19870607_20170212_01_T1 (Path 9, Row 29), Acquisition date: 7 June 1987.

Accuracy Statistics

Overall Accuracy : 69.500% 95% Confidence Interval (62.869% 76.131%)
Overall Kappa Statistic: 0.599 Overall Kappa Variance : 0.002

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Water	92.982%	(85.474% 100.491%)	92.982%	(85.474% 100.491%)	0.9019
Forest_La	63.235%	(51.040% 75.431%)	60.563%	(48.491% 72.636%)	0.4025
No_Data	100.000%	(97.368% 102.632%)	100.000%	(97.368% 102.632%)	1.0000
Urban_Bui	0.000%	(-16.667% 16.667%)	0.000%	(-10.000% 10.000%)	-0.0152
Barren_La	31.250%	(13.628% 48.872%)	76.923%	(50.173% 103.673%)	0.7253
Range_Lan	66.667%	(44.123% 89.210%)	40.000%	(22.341% 57.659%)	0.3296

Table 18: Error confusion matrix for 1987 unsupervised classification of Landsat Image ID: LT05_L1TP_009029_19870607_20170212_01_T1 (Path 9, Row 29), Acquisition date: 7 June 1987.

Error (Confusion) Matrix

Classified Data	Reference Data						
	Water	Forest_La	No_Data	Urban_Bui	Barren_La	Range_Lan	Totals
Water	53	2	0	0	2	0	57
Forest_La	4	43	0	1	17	6	71
No_Data	0	0	19	0	0	0	19
Urban_Bui	0	2	0	0	2	1	5
Barren_La	0	2	0	1	10	0	13
Range_Lan	0	19	0	1	1	14	35
Unknown	0	0	0	0	0	0	0
Totals	57	68	19	3	32	21	200

Table 19: Accuracy matrix for 1997 supervised classification of Landsat Image ID: LT05_L1TP_009029_19970922_20161230_01_T1 (Path 9, Row 29), Acquisition date: 22 September 1997.

Accuracy Statistics

Overall Accuracy : 50.000% 95% Confidence Interval (42.820% 57.180%)
Overall Kappa Statistic: 0.367 Overall Kappa Variance : 0.001

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Class-00	0.000%	(-50.000% 50.000%)	0.000%	(-2.083% 2.083%)	-0.0050
Water	72.727%	(58.431% 87.023%)	96.970%	(89.606% 104.334%)	0.9611
Urban_Bui	45.455%	(11.483% 79.426%)	20.000%	(2.320% 37.680%)	0.1534
Barren	12.903%	(-0.511% 26.317%)	28.571%	(1.336% 55.807%)	0.1547
Forest_la	55.102%	(44.744% 65.460%)	91.525%	(83.571% 99.479%)	0.8338
Rangeland	33.333%	(6.144% 60.523%)	17.241%	(1.769% 32.714%)	0.1053
Agricultu	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000

Table 20: Error confusion matrix for 1997 supervised classification of Landsat Image ID: LT05_L1TP_009029_19970922_20161230_01_T1 (Path 9, Row 29), Acquisition date: 22 September 1997.

Error (Confusion) Matrix

Classified Data	Reference Data					
	Class-00	Water	Urban_Bui	Barren	Forest_la	Rangeland
Class-00	0	10	0	3	11	0
Water	1	32	0	0	0	0
Urban_Bui	0	0	5	10	7	3
Barren	0	2	1	4	7	0
Forest_la	0	0	1	1	54	3
Rangeland	0	0	0	9	15	5
Agricultu	0	0	4	4	4	4
Unknown	0	0	0	0	0	0
Totals	1	44	11	31	98	15

Table 21: Accuracy matrix for 1997 unsupervised classification of Landsat Image ID: LT05_L1TP_009029_19970922_20161230_01_T1 (Path 9, Row 29), Acquisition date: 22 September 1997.

Accuracy Statistics

Overall Accuracy : 85.000% 95% Confidence Interval (79.801% 90.199%)
Overall Kappa Statistic: 0.780 Overall Kappa Variance : 0.001

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Class-01	94.444%	(81.085% 107.804%)	100.000%	(97.059% 102.941%)	1.0000
Water	98.148%	(93.626% 102.670%)	98.148%	(93.626% 102.670%)	0.9746
Forest_La	89.888%	(83.062% 96.713%)	81.633%	(73.456% 89.809%)	0.6691
Rangeland	42.857%	(-0.946% 86.661%)	42.857%	(-0.946% 86.661%)	0.4078
Ubran_Bui	53.125%	(34.272% 71.978%)	70.833%	(50.565% 91.102%)	0.6528
Agricultu	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000

Table 22: Error confusion matrix for 1997 unsupervised classification of Landsat Image ID: LT05_L1TP_009029_19970922_20161230_01_T1 (Path 9, Row 29), Acquisition date: 22 September 1997.

Error (Confusion) Matrix

Classified Data	Reference Data: Class-01	Water	Forest_La	Rangeland	Ubran_Bui	Agricultu	Totals
Class-01	17	0	0	0	0	0	17
Water	1	53	0	0	0	0	54
Forest_La	0	0	80	3	15	0	98
Rangeland	0	0	4	3	0	0	7
Ubran_Bui	0	1	5	1	17	0	24
Agricultu	0	0	0	0	0	0	0
Unknown	0	0	0	0	0	0	0
Totals	18	54	89	7	32	0	200

Table 23: Accuracy matrix for 2007 supervised classification of Landsat Image ID: LT05_L1TP_009029_20070902_20161112_01_T1 (Path 9, Row 29), Acquisition date: 2 September 2007.

Accuracy Statistics

Overall Accuracy : 49.500% 95% Confidence Interval (42.321% 56.679%)
Overall Kappa Statistic: 0.353 Overall Kappa Variance : 0.001

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Class-00	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000
Water	68.421%	(52.326% 84.516%)	100.000%	(98.077% 101.923%)	1.0000
Forest_La	51.961%	(41.775% 62.147%)	88.333%	(79.377% 97.290%)	0.7619
Range_Lan	20.000%	(4.020% 35.980%)	20.690%	(4.222% 37.157%)	0.0669
Urban_Bui	53.846%	(22.900% 84.792%)	24.138%	(6.839% 41.437%)	0.1886
Barren_La	41.176%	(14.840% 67.513%)	29.167%	(8.898% 49.435%)	0.2259
Agri_Land	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000

Table 24: Error confusion matrix for 2007 supervised classification of Landsat Image ID: LT05_L1TP_009029_20070902_20161112_01_T1 (Path 9, Row 29), Acquisition date: 2 September 2007.

Error (Confusion) Matrix

Classified Data	Reference Data					
	Class-00	Water	Forest_la	Rangeland	Urban_Bui	Barren
Class-00	0	3	1	0	0	0
Water	2	47	0	0	0	0
Forest_la	0	0	22	0	0	1
Rangeland	0	1	30	7	1	2
Urban_Bui	0	2	38	6	5	11
Barren	0	0	5	2	2	8
Agricultu	0	0	0	1	0	0
Unknown	0	0	0	0	0	0
Totals	2	53	96	16	8	22

Table 25: Accuracy matrix for 2007 unsupervised classification of Landsat Image ID: LT05_L1TP_009029_20070902_20161112_01_T1 (Path 9, Row 29), Acquisition date: 2 September 2007.

Accuracy Statistics

Overall Accuracy : 77.000% 95% Confidence Interval (70.918% 83.082%)
Overall Kappa Statistic: 0.680 Overall Kappa Variance : 0.001

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Water	100.000%	(99.074% 100.926%)	94.737%	(88.063% 101.411%)	0.9279
Forest_La	79.545%	(70.549% 88.541%)	85.366%	(77.106% 93.626%)	0.7387
Range_Lan	46.667%	(18.086% 75.247%)	22.581%	(6.249% 38.912%)	0.1630
Urban_Bui	16.667%	(-21.487% 54.820%)	33.333%	(-36.678% 103.344%)	0.3127
Barren_La	11.765%	(-6.492% 30.022%)	66.667%	(-3.344% 136.678%)	0.6357
Agri_Land	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000
No_Data	100.000%	(97.500% 102.500%)	100.000%	(97.500% 102.500%)	1.0000

Table 26: Error confusion matrix for 2007 unsupervised classification of Landsat Image ID: LT05_L1TP_009029_20070902_20161112_01_T1 (Path 9, Row 29), Acquisition date: 2 September 2007.

Error (Confusion) Matrix

Classified Data	Reference Data: Water	Forest_La	Rangeland	Urban_Bui	Agricultu	No Data	Totals
Water	59	0	0	3	0	0	62
Forest_La	1	41	8	9	0	0	59
Rangeland	0	13	1	6	0	0	20
Urban_Bui	0	31	6	9	1	0	47
Agricultu	0	0	0	0	1	0	1
No Data	0	0	0	0	0	11	11
Unknown	0	0	0	0	0	0	0
Totals	60	85	15	27	2	11	200

Table 27: Accuracy matrix for 2017 supervised classification of Landsat Image ID: LC08_L1TP_009029_20170913_20170928_01_T1 (Path 9, Row 29), Acquisition date: 13 September 2017.

Accuracy Statistics

Overall Accuracy : 45.500% 95% Confidence Interval (38.348% 52.652%)
Overall Kappa Statistic: 0.352 Overall Kappa Variance : 0.001

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Class-00	0.000%	(-25.000% 25.000%)	0.000%	(-10.000% 10.000%)	-0.0101
Water	88.679%	(79.205% 98.153%)	95.918%	(89.358% 102.479%)	0.9445
Forest_la	22.917%	(13.988% 31.845%)	95.652%	(85.144% 106.161%)	0.9164
Rangeland	43.750%	(16.317% 71.183%)	17.073%	(4.336% 29.810%)	0.0986
Urban_Bui	62.500%	(22.702% 102.298%)	8.065%	(0.480% 15.649%)	0.0423
Barren	36.364%	(13.989% 58.738%)	47.059%	(20.390% 73.727%)	0.4052
Agricultu	66.667%	(-3.344% 136.678%)	66.667%	(-3.344% 136.678%)	0.6616

Table 28: Error confusion matrix for 2017 supervised classification of Landsat Image ID: LC08_L1TP_009029_20170913_20170928_01_T1 (Path 9, Row 29), Acquisition date: 13 September 2017.

Error (Confusion) Matrix

Classified Data	Reference Data: Class-00	Water	Forest_La	Range_Lan	Urban_Bui	Barren_La
Class-00	0	8	3	4	0	4
Water	0	26	0	0	0	0
Forest_La	0	1	53	5	0	1
Range_Lan	0	1	20	6	0	2
Urban_Bui	0	1	17	3	7	1
Barren_La	0	1	8	5	3	7
Agri_Land	0	0	1	7	3	2
Unknown	0	0	0	0	0	0
Totals	0	38	102	30	13	17

Table 29: Accuracy matrix for 2017 unsupervised classification of Landsat Image ID: LC08_L1TP_009029_20170913_20170928_01_T1 (Path 9, Row 29), Acquisition date: 13 September 2017.

Accuracy Statistics

Overall Accuracy : 61.000% 95% Confidence Interval (53.990% 68.010%)
Overall Kappa Statistic: 0.472 Overall Kappa Variance : 0.002

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Water	98.333%	(94.261% 102.406%)	95.161%	(89.013% 101.309%)	0.9309
Forest_La	48.235%	(37.024% 59.446%)	69.492%	(56.895% 82.088%)	0.4694
Rangeland	6.667%	(-9.290% 22.624%)	5.000%	(-7.052% 17.052%)	-0.0270
Urban_Bui	33.333%	(13.700% 52.967%)	19.149%	(6.836% 31.462%)	0.0653
Agricultu	50.000%	(-44.296% 144.296%)	100.000%	(50.000% 150.000%)	1.0000
No Data	100.000%	(95.455% 104.545%)	100.000%	(95.455% 104.545%)	1.0000

Table 30: Error confusion matrix for 2017 supervised classification of Landsat Image ID: LC08_L1TP_009029_20170913_20170928_01_T1 (Path 9, Row 29), Acquisition date: 13 September 2017.

Error (Confusion) Matrix

Classified Data	Reference Data					
	Water	Forest_La	Range_Lan	Urban_Bui	Barren_La	Agri_Land
Water	54	1	0	0	2	0
Forest_La	0	70	6	0	6	0
Range_Lan	0	17	7	2	5	0
Urban_Bui	0	0	0	1	2	0
Barren_La	0	0	0	1	2	0
Agri_Land	0	0	2	2	0	0
No_Data	0	0	0	0	0	0
Unknown	0	0	0	0	0	0
Totals	54	88	15	6	17	0